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TITLE: SNAP-8 Turbine Labyrinth Seal Galling Tests

ABSTRACT

Current SNAP-8 turbines include S-816 material for the thrust, interstage labyrinth seals and rotors. Previously, Stellite 6B had been used in these areas. Operation of turbines with Stellite 6B has revealed it to have excellent resistance to galling. The screening tests described herein were devised for the purpose of determining the galling resistance characteristic of the S-816 and to compare it with Stellite 6B.

The tests are qualitative in nature and the dynamics of the labyrinth seal were not investigated.

The results of the tests reveal that S-816 resists galling at least as well as Stellite 6B. The tests also suggest that S-816 is probably a better material from the standpoint of a lower rate of weight loss.

Although normal loads up to 50 pounds were used during the tests, there was no indication whatsoever of galling, welding or transfer of material.

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NOTE: The information in this document is subject to revision as analysis progresses and additional data are acquired.

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I. INTRODUCTION

The SNAP-8 turbine is a mercury vapor driven, 4-stage, axial impulse machine. The four stages are overhung on angular contact ball bearings. Labyrinth seals are utilized in order to minimize interstage leakage where the wheel hubs pass through the nozzle diaphragms. At the extreme end of the overhang is situated a slightly larger labyrinth seal (thrust reduction seal), the purpose of which is to allow the end of the overhung shaft to be vented to the turbine exhaust pressure without incurring too great a leakage penalty. This reduces the thrust loads on the bearings.

These labyrinth seals were originally entirely free floating and were retained in their respective locations by a Spirolox ring. This free-floating attribute it was hoped would prevent any failure mode associated with rotating wheel hub/labyrinth interference which might arise as a result of shaft/bearing displacements. The probability of interference is greater at the end furthest from the bearings, i.e. the thrust reduction seal. The labyrinth dynamics induced by contact with the rotating wheel hubs (Reference 3) and the type of wear experienced indicated that some greater axial restraint was required. The labyrinth seal Spirolox retaining ring was replaced by a tapered snap ring which provided the axial clamping force. The clamping force applied by the tapered snap ring (Figures 1, 2) holds the seal against the inlet housing and nozzle assemblies respectively.

The axial load imposed by the tapered snap ring was originally uncontrolled, and generally greater than 100 pounds was needed to radially displace the labyrinth ring. This load was reduced during various turbine assemblies eventually to 10 pounds in the belief that providing the labyrinth seals can readily move out of the way when touched or struck by the rotating wheel hubs, and the force normal to the interfering surfaces is not large then no failure should arise. This is providing that there is no tendency to gall or spall during the period of contact between the stationary labyrinth and rotating wheel hub.

Testing of several SNAP-8 turbine alternators in the Power Conversion System Loop No. 1 (PCS-1) and their subsequent disassembly have revealed that interference and wear between the thrust and interstage labyrinth seals and the turbine wheel hubs had occurred (References 1 and 2, and Table 1). The degree of interference as indicated by the severity of wear varied from unit to unit. In all cases the greatest wear occurred on the thrust reduction labyrinth seal. This was to be expected since it is located at the extreme end of the overhung shaft. There did not appear to be any clear correlation between the axial clamping force and the degree of wear or interference experienced (Table 1).

The change in turbine wheel material from Stellite 6B to S-816 prompted the question as to whether the S-816 was as good as the Stellite had proved to be with regard to resistance to galling in the operation of several turbines. A simple screening test was therefore devised with the purpose of comparing S-816 with Stellite 6B regarding resistance to galling.

II. OBJECTIVES

The objectives of the material screening tests are to:

1. Compare the relative galling properties of the two materials, S-816 and Stellite 6B using actual turbine experience with Stellite 6B as a reference.

2. Recommend further evaluation and possible redesign should S-816 be unsatisfactory.

III. METHOD OF TESTING

It is not intended that the dynamics of the labyrinth/shaft simulator as it occurs in the turbine be simulated. It is important, however, that the wear patterns be reproduced as closely as possible. The physical setup must provide a similar mechanism of rubbing or interference as it is experienced in the turbine.

The parameters which influence the propensity to gall which have to be reproduced as closely as possible are:

1. Relative speed between stationary and rotating parts
2. The load normal to the contacting surfaces
3. The general environment
4. Material properties:
   a. Modulus of shear rigidity
   b. Shear strength
   c. Tensile and yield strength.
5. Material temperature in the region of contact.

The parameters (1) and (2) represent no problem in reproduction on the test rig. The general environment, i.e. mercury vapor compared with air, should not be restrictive with regard to simulation of wear. The difference between the heat sink capacity of the two fluids (the air at room temperature and the mercury vapor at 1000°F) between labyrinth and runner and in the general environment is negligible. Considering the parameter under (5) above, if all the heat generated in friction is assumed converted into a temperature rise at the point of contact, and the region of contact is assumed very small, then a temperature of the order of 1500°F to 2000°F will be generated at the point of contact under normal loads greater than about 25 pounds. The heat generated due to friction at the point of contact should therefore provide a sufficiently high temperature to ensure that the material properties will be close to those at the operating temperatures normally experienced in the turbine.

The method of testing becomes one of subjecting the rotating and stationary components under tests to steady interference loads of various magnitudes normal (as against tangential) to the mating surfaces of the labyrinth seal and shaft simulator. The magnitude of the loading and/or the time duration of application is to be extended until galling occurs or a normal load of 50 pounds is reached. The 50-lb load is primarily a limit dictated by the test rig motor.

A. TEST FIXTURE

The test fixture is shown in AGC Drawing No. 1266131 (Figure 1), and schematically in Figure 2. The fixture consists of an air-oil mist lubricated, 30 hp, 490 cycle (24,000 rpm) Task motor run at 200 cps (12,000 rpm). On the end of the motor with the shaft extension is attached a stainless steel housing which contains a turbine thrust seal recess and thrust seal and its retaining tapered snap ring. The part that simulates the hub of the first-stage wheel is attached to the motor shaft extension. The open end of the test housing is enclosed by a translucent Plexiglass cover so that the onset of any discoloration in the region of contact (an indication of high temperature) can be noted and before any serious damage can occur. The loading mechanism consists of placing the required load on a plate-like receptacle situated on the end of a rod which passes radially through the test housing and which rests on the radial rim of the labyrinth seal (Figure 2).

The recess into which the seal sits and the method of seal retention are identical to that as it exists in the turbine. Dimensionally, the entire seal, its lands and the shaft simulator are identical to the corresponding components in the turbine. In addition, the surface finish and the material condition (as dictated by an identical heat treatment) are the same as the parts would have been if incorporated in a turbine assembly.

B. MODE OF TESTING

The initial objective of the test was to obtain wear characteristics similar to those obtained in the turbine assembly, Figures 3, 4 and 5, during mercury operation. The wear characteristics that were obtained during actual TAA tests in PCS-1 varied from what may be described as "very light" to "heavy." The primary difference between the two extremes of wear is the depth of the grooves worn in the rotating member and the general appearance of the parts (Figures 3, 4 and 5).

Prior to any tests being conducted, the significant dimensions (Figures 16 and 17) and the weights of the labyrinth seal and runner specimens were obtained. It was anticipated that as the magnitude of the imposed loads increased that the spectrum of wear patterns would simulate the range of wear obtained during turbine tests at least as far as the "medium" wear.

The initial test was conducted with a Stellite 6B labyrinth and runner followed by an identical test (in regard to applied load and period of application) with a S-816 labyrinth and runner. After the test, the parts were reweighed and dimensionally inspected and photographed.

The process was continued in seven unequal steps from an initial load of 150 grams (0.349 lb) to a final load of 22,000 grams (50 lb).

Examination of both sets of specimens (the Stellite 6B and S-816) after approximately a 5 minute load application of 150 grams indicated an immeasurable amount of material removal from both the rotating and stationary parts. The time period was then extended to 1 hour for the loads up to 4.5 lb. As the loads were increased, the period of application was reduced considerably in order that the bearings of the motor and the motor itself would not be endangered. A failure of the motor bearing closest to the test section could seriously mar the test specimens enough to void their further use. It was found

that a modification to the mechanism retaining the labyrinth seal was required in order for the tests to function properly. Since the initial loads to be applied were less than the axially applied clamping force (~30-50 lb) imposed on the labyrinth by the tapered snap ring, in order for the labyrinth to be able to contact the runner under these light radial loads the axial clamping force had to be reduced to something less. The tapered snap ring was therefore ground down until the labyrinth as in the housing was just free to move radially under its own weight.

The labyrinth seal was prevented from spinning by an antirotation pin located on a tangent passing through the point of contact of the stationary labyrinth and rotating runner (Figures 1 and 16).

IV. TEST RESULTS

A. OBSERVED PHENOMENA

1. Dynamic

Generally, there was little to observe during any of the tests. The initial few moments after the application of any load were accompanied by some minor oscillation and chatter as surface irregularities and any discontinuities were worn down. Thereafter the motion of the seal (as transmitted externally to the housing via the loading pin) was stable with an apparent underlying very high frequency (very low amplitude) vibration. At the higher loads (above 5 lb) the intensity of the initial vibration period became more intense but again became stable after a few moments. It was only at the highest load that any discoloration in the region of contact was noticed and after 1.25 minutes of load application the motor speed started to decrease and the motor current increased rapidly. Only under these circumstances had the frictional force generated become sufficiently high to affect the motor operating characteristics. In order to safeguard the motor and the test specimens the high current trip was set at about 10 amps compared with the normal running current of 6 amps.

2. Appearance of Specimens

Photographs of the labyrinth seal lands in the region of contact and O.D. of the runner of both the Stellite 6B and S-816 specimens are shown in Figures 8 through 15.

The surface of the lands before testing (Figure 7) and the surface of the runners were found to be a 32 finish. The rubbed surface of the labyrinth lands prior to testing showed machining marks (Figure 7). However, these marks were soon obliterated. The contacted surface of the labyrinth became dark gray and gave the appearance of having been exposed to a light grinding action. The runners of both specimen materials showed circumferential ring grooves corresponding to the location of the labyrinth seal lands. There was some circumferential variation in regard to the intensity of the wear marks on the runners; this was primarily due to the slight eccentricity (0.0005 inch) of the runner and motor shaft.

As the load levels were increased, the contacting surfaces of runners and labyrinths of both specimens became darker in color, the contacting surfaces on the I.D. of the labyrinths became distinctly rougher (Figures 8 through 15). Above the 15-lb load it was observed on removal of the specimens for examination, a fine carbon-like powder was deposited on the I.D. of the test housing and more was found in the bottom of the labyrinth seal grooves. The amount of powder found increased as the applied load increased. Metallurgical analysis of the carbon-like material is covered in paragraph D.

It was only at the 50-lb load level that any discoloration due to heat generation occurred, mainly on the labyrinth. The discoloration indicated that a temperature of the order of about 1500-1800°F had been generated at the point of contact. At no time was there any transfer of material from either labyrinth to runner or vice versa.

B. WEIGHT LOSS

Both labyrinth seals and runners were weighed before testing commenced and after each load application. The results are plotted in Figures 18 and 19.

Since the period of load application was reduced as the load increased, the weight loss is plotted as a rate (grams/minute) thus minimizing the influence of the period of load application.

In both instances in regard to the labyrinth seal, after the initial weight loss, weight loss rate-load characteristics are identical. Somewhere between the 25-lb and 40-lb load the rate of material removal increased markedly. It appears that the only difference between the two characteristics is the initial weight loss which has effectively displaced the Stellite 6B curve upward and away from the S-816 characteristic. Providing this initial weight loss displacement is real, it would appear that the S-816 is disposed to lose less material than the Stellite 6B within the limits established by this test.

The shaft simulator characteristic (Figure 19) shows an altogether different picture. The Stellite runner after the initial weight loss appears to lose material at a linearly increasing rate. The S-816 runner, however, loses little material initially and thereinafter the rate of material loss appears to actually decrease.

C. DIMENSIONAL CHANGES

1. Labyrinth Seal

The dimensional changes of the labyrinth seals and the runners are shown in Tables 2 and 4. The results in both instances were not unexpected in light of the weight loss characteristics, particularly for the runners. The labyrinth seal internal diametral increase seems to indicate that directly under the load (at the point of contact), i.e., in Figure 16, D.3, the S-816 labyrinth had the larger change in dimension whereas at points furthest from the point of contact, i.e. D_1 and D_4, the Stellite 6B had the greater dimensional I.D. change.

This difference in wear could easily be brought about by slightly different seal dynamics. Examining the location of the antirotation pin, which is initially on a tangent through the point of contact (Figure 2), it is not difficult to see that as wear occurs in both labyrinth and runner that the tangential friction force will no longer pass through the pin center and the original equilibrium condition is upset. This upset can be aggravated by any degree of eccentricity or runout of the shaft simulator or shaft and the variation in fabrication tolerances (which are identical to those tolerances imposed on the corresponding parts installed in a turbine). It is not intended to pursue the possible dynamics of the seal and runner except to point out that

the weight loss rate noted in Figure 18 may be misleading. However, it is highly likely, that at least from a weight loss rate standpoint that S-816 is at least as good as Stellite 6B for turbine labyrinth and rotor parts.

2. Shaft Simulator

The grooves in the shaft simulator show, in general, increasing depth with increasing load (Tables 2 and 4). It is noticeable that the grooves formed to the rear of the runner appear to be deeper than those at the front. This suggests some cocking and possibly some uneven loading, particularly in the axial loading provided by the tapered snap ring. This is possible considering the loading is applied to the flange of the labyrinth, which is located to the rear of the seal.

D. METALLURGICAL FINDINGS

1. Type of Examination

Metallurgical examination of the parts that were tested and the residue found consisted of the following:

a. Emission spectrographic analyses of residue samples obtained from the abraded labyrinth material that collected in the test fixture housing during all testing of the Stellite 6B (30 Cr, 3 Ni, 3.5 W, 53 Co-base) and S-816 superalloy (20 G, 20 Ni, 4 Co-base) seals and runners and from residues adhering to the individual labyrinths: carbon analysis and X-ray diffraction tests of the residue from the test fixture.

b. Longitudinal cross sections cut from the Stellite 6B and S-816 labyrinth seals and runners after testing prepared metallographically for macroscopic and microscopic examinations at magnifications up to 150X. The seal sections were taken through the lands in the contact areas that exhibited a blue heat-affected surface, which resulted from the testing, and at the unexposed areas 180 degrees away. Cross sections of the Stellite 6B and S-816 runners were also obtained for examination of the heat-affected areas and at the opposite diametrical surface. Micro-hardness surveys were conducted on the unexposed and exposed regions of the seals and runners.

2. Evaluation of the Results

The emission analyses results (± 25% accuracy) of weight percent of metallic elements in the residues and of the carbon and hydrogen present and the XRD results are as follows:

Element	Alloy Composition (Weight - %)		Recovered Residue Analysis (Weight - %)		
	6B	S-816	Fixture Housing	6B Labyrinth	S-816 Labyrinth
Co	57	43	55.4	67.5	54.1
Ni	3	20	9.7	4.2	12.8
Cr	30	20	12.4	16.0	7.7
Fe	3	3	6.3	0.8	9.4
C	-	4			
Mo	1.5	4	1.8	ND*	3.3
W	4.5	4			
Mn			1.2	1.1	1.1
C	1.0	.40	0.58	ND	ND
H	-	-	0.14	ND	ND

*ND indicates not determined.

XRD showed no carbides in residue from fixture housing.

A comparison of the spectrographic data indicates that the general composition characteristics of the metallic residues were similar and that the housing residues resulted from labyrinth seal material removal. The small percentage of carbon and hydrogen in the "housing" residue is ascribed to trace organic or absorbed moisture contamination introduced during system assembly and/or carbon in the Stellite 6B. The lack of carbides in the general residue indicates that an insufficient amount for detection of the microstructural phase was abraded from the contact surfaces during testing.

The appearance of the labyrinth-seal cross sections of the unexposed and exposed lands is shown in Figure 20. A comparison of Figures 20A and 20B shows that the Stellite 6B seal displayed appreciably less metal deformation than the S-816 part as indicated by the reduction in height of the lands. The Stellite 6B material showed the smaller amount of curling and metal displacement at the edges of the lands probably because metal fragments

broke off the 6B part as the deformation occurred rather than curling as the S-816 did. This would be expected because of the significantly higher hardness and greater quantity of brittle carbide phase associated with the 6B. The lands of both seals of the S-816 part at the circumferential collar upon which the test load was applied showed the greatest reduction in height, the amount decreasing progressively toward the opposite face. No actual galling, per se, or welding of metal on the surfaces of the lands of either seal material was observed. Figures 21 and 22 show comparison of the as-machined (unexposed) and exposed land profiles at the contact surface of each seal. The as-machined Stellite 6B surface, Figure 21A, exhibited a coarser finish than the corresponding surface of the S-816 part which also showed some machining burrs, Figure 22A. However, the abraded Stellite 6B surface, Figure 21B, was smoother than the contacting surface of the S-816 seal, Figure 22B. The smoother Stellite 6B surface is attributed to the higher base-metal hardness, which is described subsequently.

The microstructural examination of the unexposed and exposed Stellite 6B lands at X150, Figure 23, revealed that no structural change occurred at the rubbed surface and that the alloy had ASTM No. 10 grain size, normally seen in the steel. The microstructures of the unexposed and exposed S-816 lands are shown in Figure 24. A much larger grain size (ASTM No. 1-1/2 to 2) and a greater degree of metal curling or displacement were present in the alloy. The grain size is larger than that (No. 6 to 9) normally observed in properly processed material, probably resulting from the heating effect of the test. However, it is not expected that larger grain size would be a major factor accountable for the greater metal deformation at the land; rather, the hardness property of an alloy is considered to be one of the important controlling characteristics.

A small amount of wear of about .0005 in. and grain growth were present in the heat-affected region of the "wear groove" in the Stellite 6B runner, Figure 25A, when compared with that of the unaffected runner area 180° away, Figure 25B. The grain growth and heat-affected area were probably caused by the surface temperature (1800°F estimated) that resulted from the rubbing of the lands on the runner and the subsequent contact period until the parts could be disassembled after gall testing. The S-816 alloy runner exhibited a slightly smaller amount of wear (about .0003 in.) in the heat-affected contact

surface, Figure 26A, than the corresponding area of the Stellite 6B runner. Grain growth also occurred in the heat-affected region of the Stellite 6B runner. Grain growth also occurred in the heat-affected region of the S-816 alloy as exemplified by the No. 2-1/2 grain size, Figure 26A, versus a mixed grain size of No. 3 to 8 in the diametrically opposite surface, Figure 26B.

In Table 6 are tabulated the equivalent Rockwell C hardness of the unexposed and exposed sections of the labyrinth seals and runners after testing. The unexposed Stellite 6B seal land showed hardness in the range 54 to 58 R_c compared to 51 to 54 R_c for the unexposed land, which exhibited a lower hardness of 51 R_c at the contact surface than at the O.D. (54 R_c). The lower hardness at the rubbed surface resulted from the heating, as previously described, during testing. The unaffected area of the Stellite 6B runner displayed hardness similar to that of the unexposed seal land whereas the 49 to 53 R_c hardness range of the runner heat-affected region was slightly lower than that of the exposed land. The S-816 unexposed and exposed seal lands had hardness ranges of 32 to 35 R_c and 30 to 34 R_c, while the corresponding unaffected and heat-affected areas of the runner were 28 to 33 R_c and 27 to 30 R_c, respectively. The overall data show that the base metal hardness of the Stellite 6B was, in general, about 20 R_c points higher than that shown by the S-816 alloy. The higher hardness of the Stellite 6B resulted from the prior heat treatment given the fabricated part to stabilize against elevated temperature reaction observed previously on Stellite 6B parts and presumably accounts for the smaller amount of metal deformation and smoother abraded contact surface observed on the seal.

V. DISCUSSION

The tests were derived as a simple screening technique to indicate as to whether the combination of an S-816 labyrinth seal and runner was as resistant to galling as Stellite 6B has proved to be in the turbine tests in PCS-1.

Apart from the possible influence of labyrinth dynamics on the weight loss rate characteristic, under none of the load conditions did the S-816 exhibit any tendency to gall or spall.

Considering for a moment the circumstances likely to be encountered during labyrinth seal turbine rotor interference, the nature of the contact is likely to be impulsive (of very short duration) and the normal (as against tangential) load occurring between the contacting surfaces will be a function of the axial clamping force and the coefficient of friction between the labyrinth flange and its seat.

The labyrinth seals are assembled in the turbine-alternator assembly with an axial clamping force sufficient to require a force of approximately 10 pounds or less to move them radially.

It is more than likely that the 50-lb load and the time period of application during these tests represent a more severe condition than the components experience during turbine operation.

One of the most interesting results of the test is the mechanism of material removal from the labyrinth/shaft simulator. The action appears to be one of grinding. The surfaces of the contacting regions to all intents gives the appearance of having been exposed to a fine grinding wheel. The fine powder found in the proximity of the labyrinth and runner seems to support this type of action.

VI. CONCLUSIONS AND RECOMMENDATIONS

1. The metallurgical and physical examination of the parts subjected to the rubbing action supports the contention that any tendency to gall is entirely absent under the conditions of testing covered herein.

2. The conditions of testing in regard to the combination of load level, duration of load application, and the temperature level of the contacting surfaces are believed to have been as severe as the equivalent parts are subjected to in the turbine during mercury service.

3. As a result of the foregoing statements, it is concluded that the material, S-816 is an entirely satisfactory replacement for Stellite 6B in regard to resistance to galling.

It is recommended that Stellite 6B labyrinth seals be replaced with seals made of S-816.

REFERENCES

1. Aerojet Technical Memorandum 4932:65-5-332, W. M. Waters, "Failure Analysis of the SNAP-8 Turbine-Alternator Assembly 3/2, S/N A-3."

2. Aerojet Technical Memorandum 4932:68-511, C. S. Mah, "Mechanical Evaluation of Turbine 5/3 after 2122 Hours of Operation in PCS-1."

3. Aerojet Technical Memorandum 4931:67-504, G. B. Bosco, "Analysis of Turbine Labyrinth Seal Oscillation."

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4932-68-0067:JRP:hw

TABLE 1

SNAP-8 TURBINE RUB HISTORY

TAA Unit	Nominal Radial Clearance	Operating Time	No. of Starts	Labyrinth Rub on First-Stage Wheel Hub	Comments on Seal
3/2	.005"	820 hr	40	Heavy	Floating (Failure - wheel/ nozzle breakup)
2/3	.005"	142 hr	3	Moderate	Fixed, clamping force > 100 lb
5/2	.005"	42 hr	2	Very heavy	Fixed, clamping force > 100 lb (Alternator runaway)
6/1	.005"	117 hr	3	Light	Fixed, clamping force < 50 lb
2/4	.005"	165 hr	7	Moderate	Fixed, clamping force < 50 lb (Amalgam deposits)
1/5 (includes 1/4)	.005"	386 hr	10	Heavy	Fixed, clamping force < 50 lb (Failure - wheel break-up)
6/2	.005"	1445 hr	4	Light/Moderate	Fixed, clamping force < 50 lb (Cracked first-stage wheel)
5/3	.008"	2123 hr	9	Moderate	Fixed, clamping force < 10 lb
5/4	.008"	Operating	-	-	Fixed, clamping force < 10 lb
7/1	.008"	-	-	-	Fixed, clamping force < 10 lb

TABLE 2

GALLING TEST

DIMENSIONAL CHANGES

Material (Labyrinth and Simulator)	LABYRINTH SEAL					SHAFT SIMULATOR									
	Load gram (lb)	D_1 (in.)	D_2 (in.)	D_3 (in.)	D_4 (in.)	D_1 (in.)	D_2 (in.)	h_1 (in.)	h_2 (in.)	h_3 (in.)	h_4 (in.)	h_5 (in.)	h_6 (in.)	h_7 (in.)	h_8 (in.)
Stellite 6B	0 (0)	1.6000	1.6000	1.6001	1.6001	1.5897	1.5894	-	-	-	-	-	-	-	-
Labyrinth P/N 099779-1, S/N A-1	156	1.6015	1.6012	1.6014	1.6016 (Front)	1.5891	1.5892	.00023	.00043	.00071	.00062	.00062	.00122	.00141	.00122
	(.349)	1.6008	1.6006	1.6008	1.6009 (Back)			.00011	.00016	.00017	.00039	.00074	.00089	.00117	.00008
	256	1.6015	1.6012	1.6014	1.6016 "	1.5890	1.5891	.00033	.00055	.00058	.00051	.00042	.00096	.00104	.0010
	(.572)	1.6008	1.6006	1.6008	1.6009 "			.00009	.00014	.00016	.00063	.00083	.00087	.00118	.00013
	482	1.6015	1.6013	1.6014	1.6017 "	1.5890	1.5890	.00033	.00048	.00056	.00054	.00032	.00055	.00094	.00056
Shaft Simulator P/N 1266165-2, S/N A-2	(1.08)	1.6010	1.6009	1.6009	1.6011 "			.00009	.00018	.00036	.00037	.00082	.00082	.00123	.00012
	2,000	1.6012	1.6013	1.6011	1.6013 "	1.5890	1.5890	.00023	.00016	.00007	.00042	.00059	.00076	.00023	.00027
	(4.5)	1.6010	1.6012	1.6010	1.6009 "			.00027	.00039	.00026	.00042	.00048	.00130	.00126	.00121
	7,000	1.6010	1.6010	1.6010	1.6010 "	1.5893	1.5893	.00051	.00072	.0010	.00094	.00112	.00152	.00187	.00083
	(15.5)	1.6009	1.6012	1.6008	1.6008 "			.00023	.00022	.00014	.00022	.00029	.00043	.00066	.00051
	11,000	1.6019	1.6021	1.6028	1.6019 "	1.5895	1.5894	.00066	.00068	.00099	.00087	.00121	.00172	.00183	.00101
	(25)	1.6013	1.6036	1.6038	1.6013 "			.00019	.00021	.00030	.00038	.00042	.00063	.00164	.00056
	22,000	1.6018	1.6068	1.6070	1.6017 "	1.5893	1.5893	.00073	.00094	.00107	.00103	.00118	.00203	.00216	.00132
	(50)	1.6036	1.6091	1.6109	1.6018 "			.00014	.00022	.00018	.00028	.00066	.00048	.00111	.00062

TABLE 3

GALLING TEST

WEIGHT CHANGE

LABYRINTH P/N 099779-1, S/N A-1 SHAFT SIMULATOR P/N 1266165-2, S/N A-2

Material (Labyrinth and Simulator)	Load gram (lb)	Labyrinth Weight (gram)	Shaft Simulator Weight (gram)
Stellite 6B	0	75.633	260.272
	156 (.349)	75.633	260.270
	256 (.572)	75.573	260.210
	482 (1.08)	75.541	260.175
	2,000 (4.5)	75.503	260.158
	7,000 (15.5)	75.477	260.127
	11,000 (25)	75.458	260.117
	22,000 (50)	75.331	260.109

TABLE 4

GALLING TEST

DIMENSIONAL CHANGES

Material (Labyrinth and Simulator)	LABYRINTH SEAL					SHAFT SIMULATOR									
	Load gram (lb)	D_1 (in.)	D_2 (in.)	D_3 (in.)	D_4 (in.)	D_1 (in.)	D_2 (in.)	h_1 (in.)	h_2 (in.)	h_3 (in.)	h_4 (in.)	h_5 (in.)	h_6 (in.)	h_7 (in.)	h_8 (in.)
S816	0 (0)	1.6069	1.6069	1.6070	1.6070	1.5907	1.5905	-	-	-	-	-	-	-	-
Labyrinth P/N 099779-1, S/N A-1	156 (.349)		Omitted							Omitted					
	256 (.572)	1.6070 1.6071	1.6073 1.6074	1.6072 1.6072	1.6070(Front) 1.6090(Back)	1.5905	1.5905	.00003 0.0	.00002 0.0	.00004 0.0	.00003 0.0	.00003 0.0	.00002 0.0	.00004 0.0	.00004 .00001
Shaft Simulator P/N 1266165-2, S/N A-2	482 (1.08)	1.6072 1.6073	1.6075 1.6075	1.6077 1.6078	1.6072 " 1.6073 "	1.5905	1.5905	.00002 0.0	.00002 0.0	.00003 0.0	.00002 0.0	.00003 0.0	.00004 0.0	.00006 0.0	.00005 .00002
	2,000 (4.5)	1.6070 1.6070	1.6076 1.6078	1.6091 1.6089	1.6070 " 1.6069 "	1.5904	1.5904	.00005 .00011	.00019 .00014	.00024 .00012	.00033 .00010	.00026 .00003	.00027 0.0	.00021 0.0	.00016 0.0
	7,000 (15.5)	1.6067 1.6069	1.6078 1.6078	1.6097 1.6107	1.6078 " 1.6078 "	1.5906	1.5906	.00017 .00022	.00022 .00021	.00026 .00025	.00032 .00017	.00029 .00009	.00022 .00012	.00027 0.0	.00019 0.0
	11,000 (25)	1.6069 1.6070	1.6077 1.6086	1.6105 1.6121	1.6069 " 1.6069 "	1.5908	1.5909	.00037 .00042	.00041 .00034	.00029 .00026	.00032 .00031	.00035 .00018	.00028 .00008	.00027 0.0	.00016 0.0
	22,000 (50)	1.6095 1.6098	1.6099 1.6108	1.6141 1.6183	1.6098 " 1.6098 "	1.5907	1.5907	.00028 .00023	.00032 .00018	.00033 .00011	.00037 .00013	.00036 .00008	.00036 .00006	.00038 0.0	.00028 0.0

TABLE 5

GALLING TEST

WEIGHT CHANGE

LABYRINTH P/N 099779-1, S/N A-1 SHAFT SIMULATOR P/N 1266165-2, S/N A-2

Material (Labyrinth and Simulator)	Load gram (lb)	Labyrinth Weight (gram)	Shaft Simulator Weight (gram)
S816	0	78.372	267.308
	156 (.349)	-	-
	256 (.572)	78.369	267.290
	482 (1.08)	78.344	267.289
	2,000 (4.5)	78.326	267.280
	7,000 (15.5)	78.305	267.279
	11,000 (25)	78.290	267.273
	22,000 (50)	78.198	267.282

TABLE 6

MICROHARDNESS RESULTS ON HEAT-TREATED STELLITE 6B[1] AND S-816[1] SUPERALLOY LABYRINTH SEALS AND RUNNERS AFTER TESTING

Hardness Location (in.)	R_c Hardness[2]							
	Stellite 6B				S-816			
	Seal (Land)		Runner		Seal (Land)		Runner	
	Unexposed	Exposed	180° from HAZ	HAZ[3]	Unexposed	Exposed	180° from HAZ	HAZ
Contact Surface	-	-	-	-	-	-	-	-
.002	54	51	56	53	32	31	31	30
.004	55	54	53	53	35	34	30	28
.008	58	54	56	50	35	31	29	29
.012	57	53	53	48	32	33	28	27
.016	55	51	54	51	33	31	30	29
.026	54	52	53	49	34	30	35	28
.036	56	54	54	51	32	32	30	29
.046	55	54	57	52	32	31	30	29
.002	55	54	54	53	35	33	33	30
Opposite Surface	-	-	-	-	-	-	-	-

(1) Heat Treatment: Stellite 6b - 2250°F, 2 hrs, RAC; 1650°F, 4 hrs, followed by 1250°F, 48 hrs, AC.
S-816 - 2210°F, 1 hr, WQ; 1400°F, 20 hrs, AC.

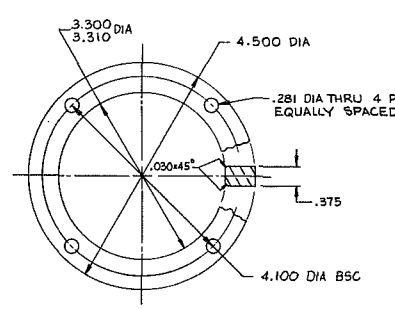
(2) Equivalent R_c hardness results for 300-gram microhardness test.

(3) HAZ denotes heat-affected zone.

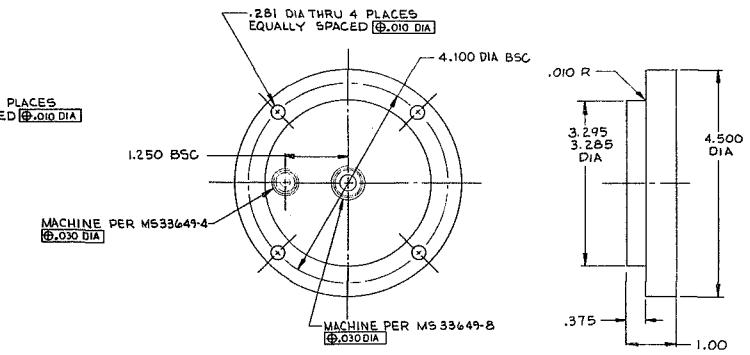
NOTES:
1. REMOVE ALL BURRS AND SHARP EDGES
2. INTERPRET DRAWING PER MIL-D-1000.
3. MACHINED SURFACES TO BE 125 UNLESS OTHERWISE SPECIFIED.
4. MATERIAL PER ANY FEDERAL, MILITARY, AERONAUTICAL OR COMMERCIAL SPECIFICATION IS ACCEPTABLE.
5. GAS TUNGSTEN ARC WELD PER AGC 10227 USING ITEM 23 WELD ROD. WELDER QUALIFICATION PER MIL-T-5021, CLA.
6. SOURCE OF SUPPLY: TASK CORPORATION, ANAHEIM, CALIF.
7. IDENTIFY ASSY PER ASD 5215 M WITH 1266131-1/(APPLICABLE REVISION LETTER).

REVISIONS

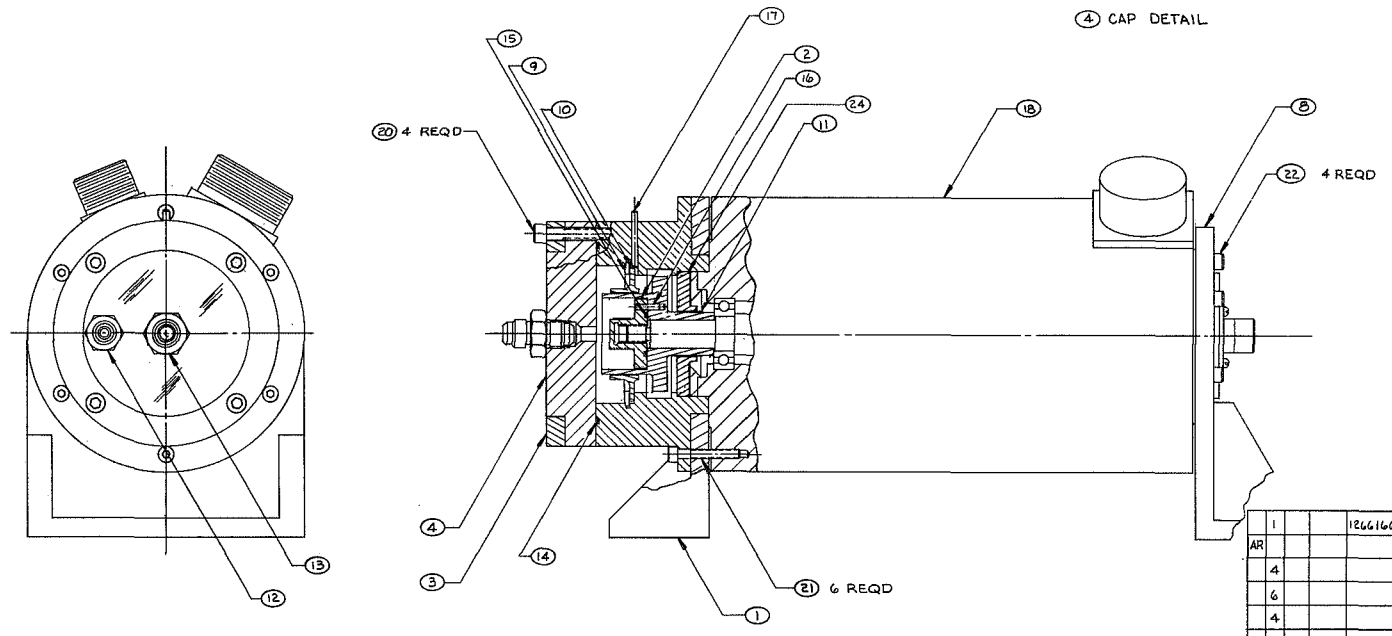
ZONE	LTR	DESCRIPTION	DATE	APPROVED

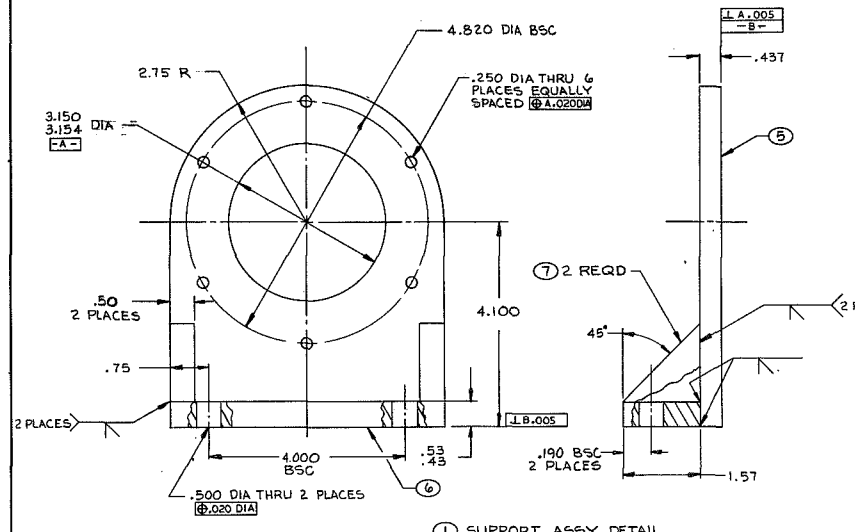


③ RING DETAIL

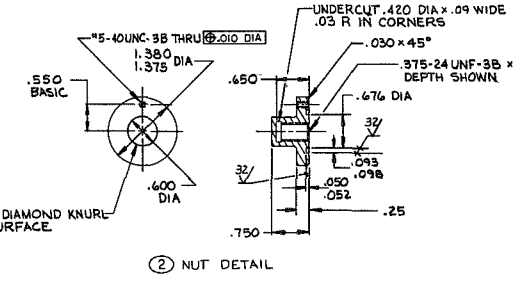


④ CAP DETAIL





① SUPPORT ASSY DETAIL



② NUT DETAIL

QTY REQD	SYM	CODE IDENT	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	UNIT WT.	ZONE	ITEM NO.
-2 -1				LIST OF MATERIALS					
1			1266166-1	SEAL					24
AR				WELD ROD	MILD STEEL	MIL-R-5632 CL2			23
4				SCH CAP SCREW	10-24UNC x .750 DEEP, ALLOY STEEL				22
6				SCH CAP SCREW	10-32UNF x 1.50 LONG, ALLOY STEEL				21
4				SCH CAP SCREW	.250-20UNC x 1.25 LONG, ALLOY STEEL				20
									19
1		A	001863	MOTOR ASSY					18
1				DOWEL PIN	.125 OD x 1.125 LONG TOOL STEEL				17
1				SETSCREW	.125-40UNC x .500 LONG, ALLOY STEEL				16
1			NAS1593-017	PACKING					15
1			NAS1593-013	PACKING					14
1			AN815-8D	UNION					13
1			AN815-4D	UNION					12
1			1266165-1 OR 1266165-2	SHAFT					11
1			0987181-1 OR 1266116-1	SEAL					10
1			0988381-1	RING					9
1			1-049774-5	SUPPORT					8
2			-9	GUSSET	MILD STEEL	A			7
1			-8	PLATE	MILD STEEL	A			6
1			-7	PLATE	MILD STEEL	A			5
1			-6	COVER	PLEXIGLAS SHEET	A			4
1			-5	RING	CRES 316 COND A	A			3
1			-4	NUT	CRES 316 COND A	A			2
1			-2	SUPPORT					1

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES. TOLERANCES ON DECIMALS: XX in. ±.03, XXX in. ±.010. DO NOT SCALE DRAWING. ANGULAR ±2°.
CONTRACT NO. NAS 5-417
DRAWN P. BECK 1-17-68
CHECK
ENGR APPV Ray 1-16-68
PRODUCTION
QUALITY APPV
CUSTOMER APPV R.C. Foley 2-8-68
TREATMENT
FINISH
SIMILAR TO
ACT. WT/CALC WT
DRAWING LEVEL 0
-1 FINAL AGAN-0010
PART BEST FINAL NEXT ASSY USED ON
NO QTY REQD APPLICATION
NO. REQ'D ASSY

AEROJET-GENERAL CORPORATION
AZUSA, CALIFORNIA

TITLE
SEAL SIMULATOR - TURBINE LABYRINTH

DWG SIZE E | CODE IDENT NO. 70143 | DWG NO. 1266131
SCALE X | REL DATE 2.8.68 | SHEET

Figure 1

668-NF-1187

GALLING TEST FIXTURE

Schematic

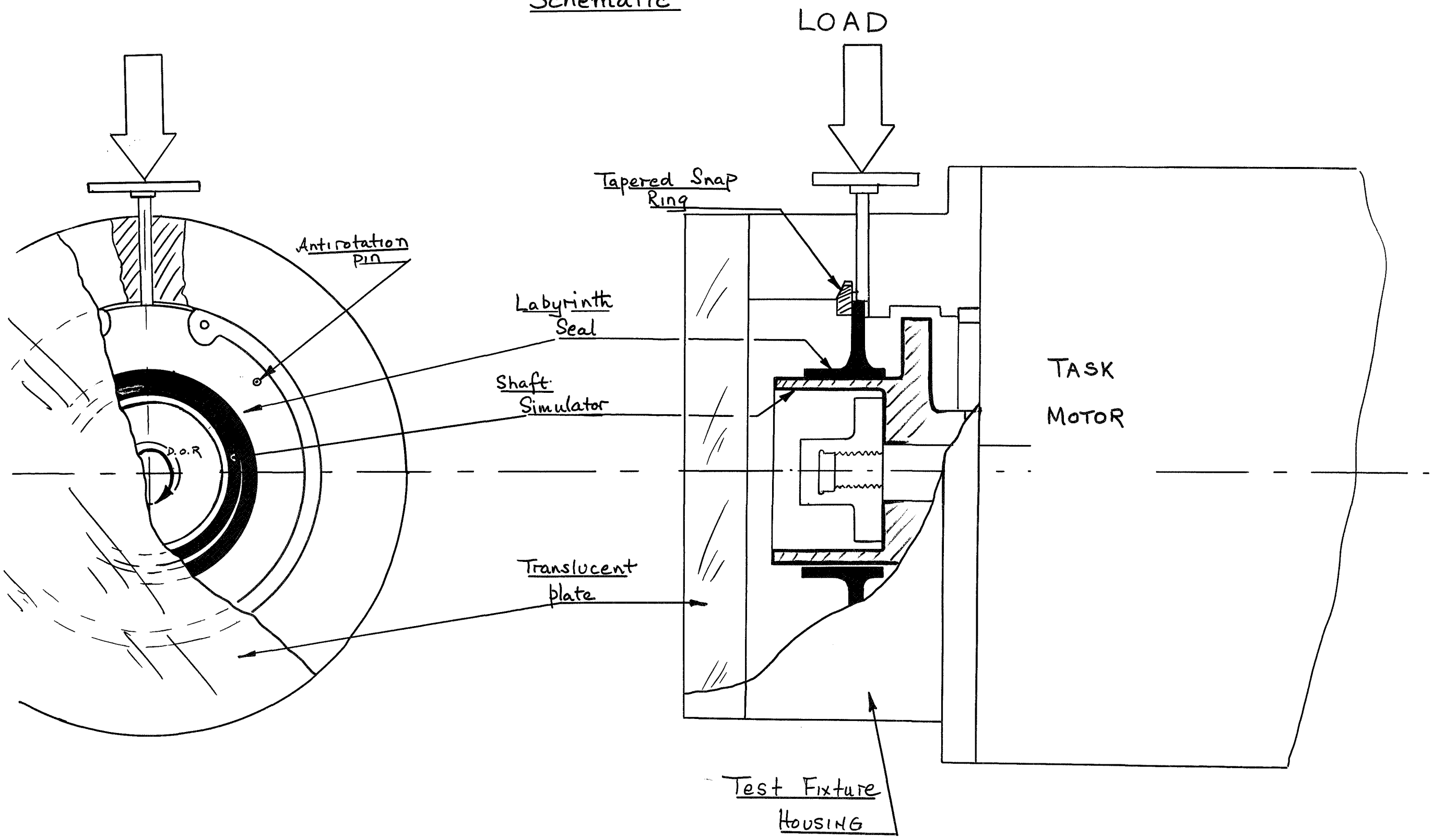
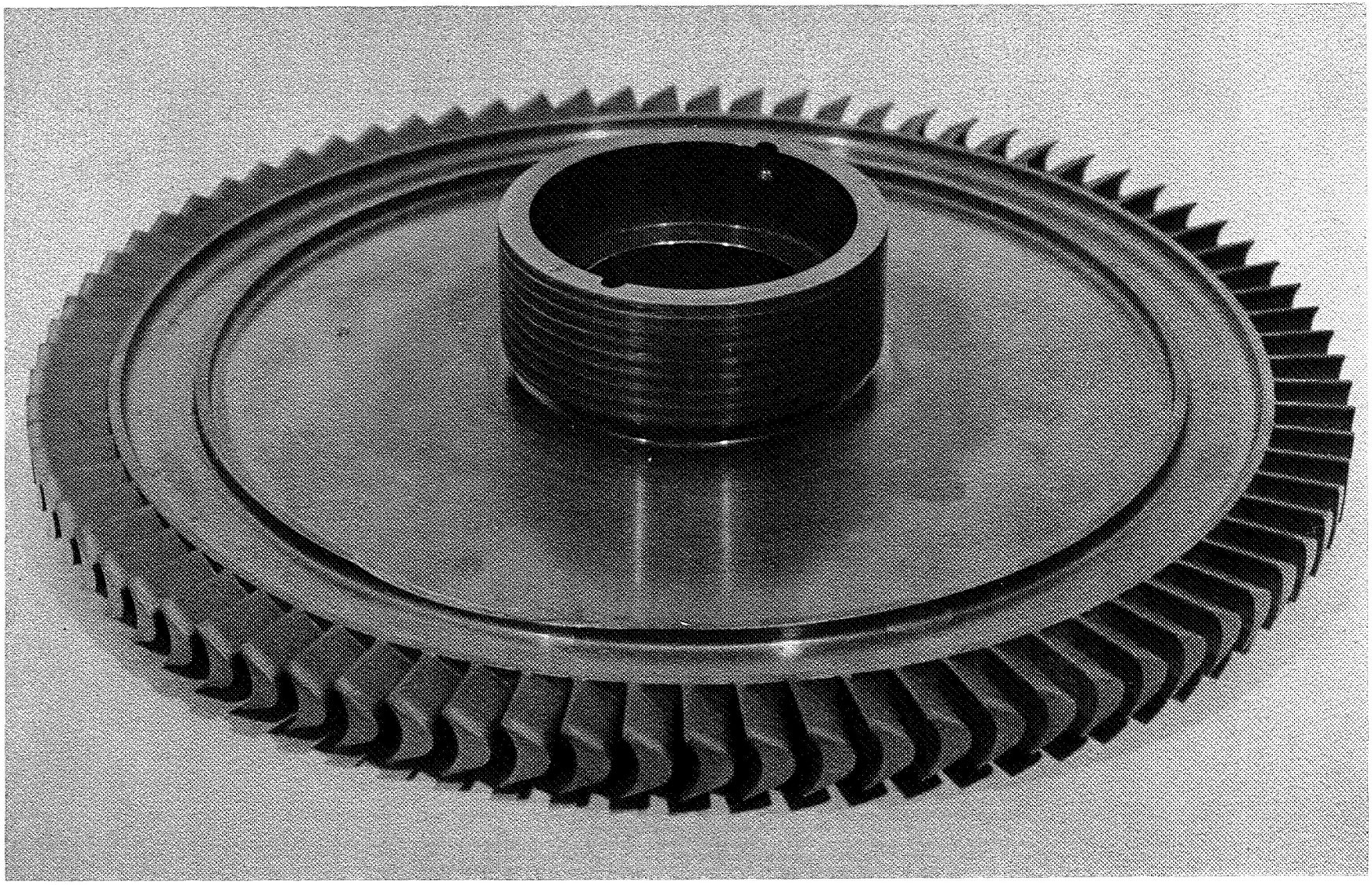


Figure 2

Figure 3



366-56

SNAP 8 TURBINE-ALTERNATOR ASSEMBLY 2/3
P/N 096800-1, S/N A2 141 HRS. OPERATION
1ST STAGE WHEEL, FRONT

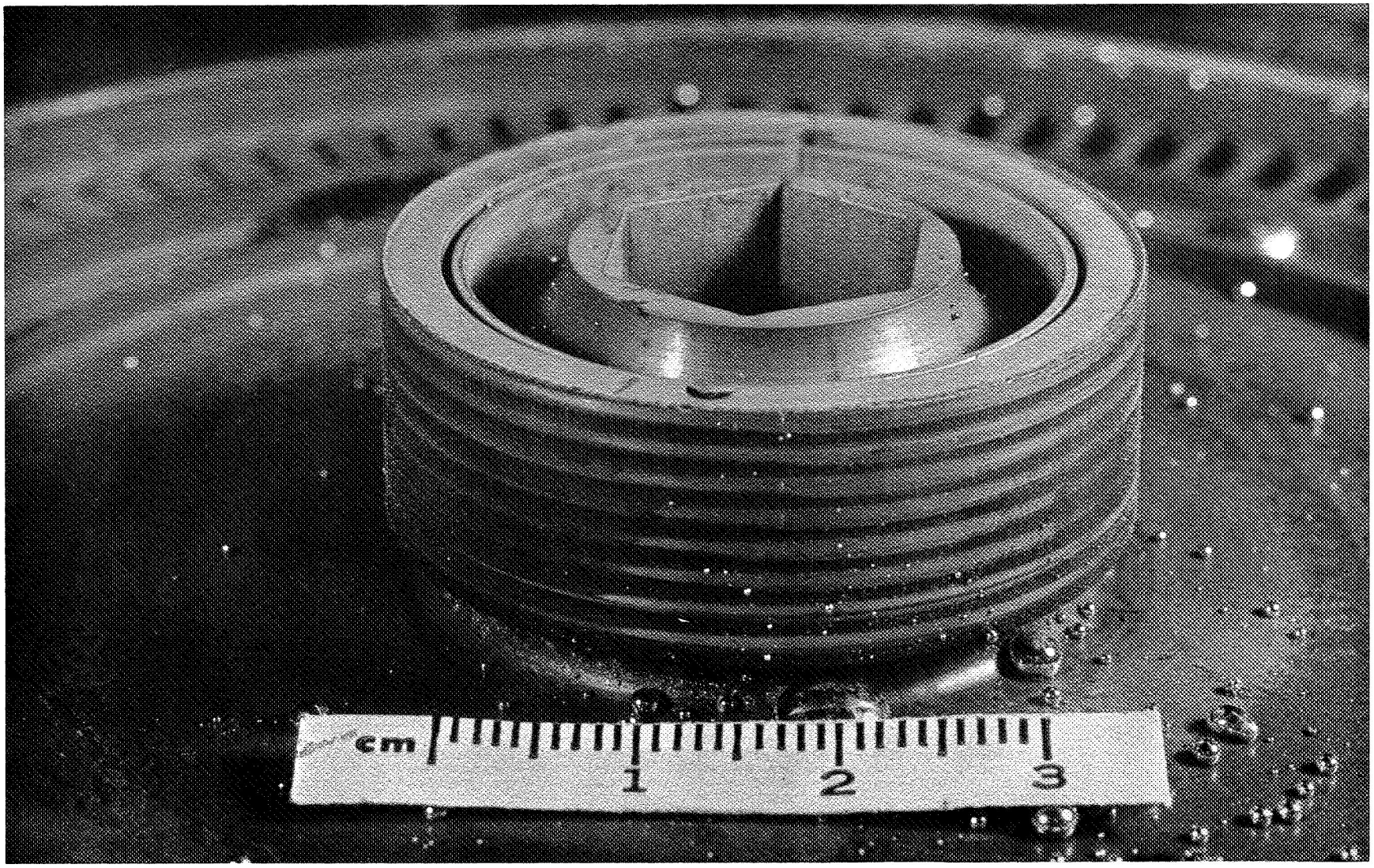


Figure 4

1167-584

SNAP-8 TURBINE-ALTERNATOR ASSEMBLY UNIT NO. 5/3
P/N 096800-5 AFTER 2123 HOURS OPERATION
FIRST STAGE WHEEL HUB SHOWING HIGH POINT
OF ECCENTRICITY WITH HEAVIEST LABYRINTH WEAR

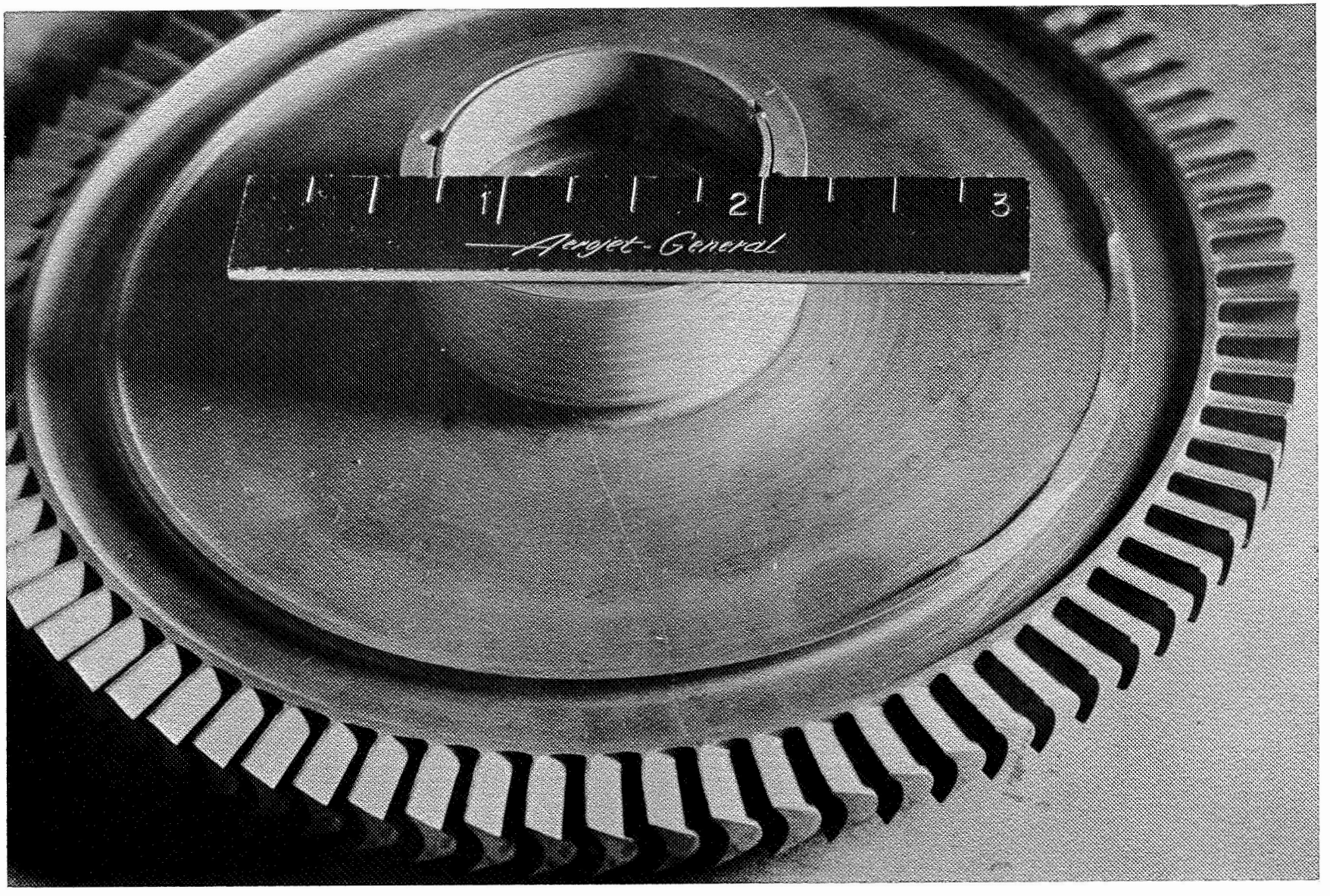
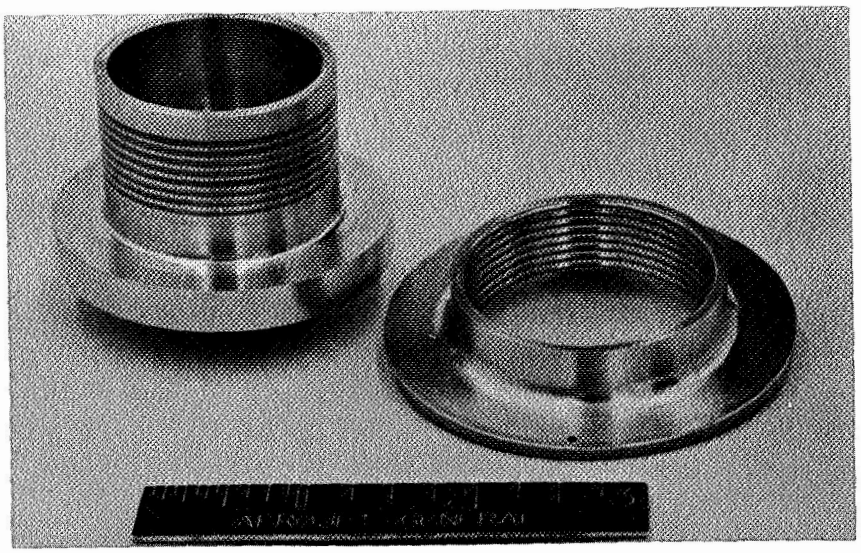


Figure 5

368-134

TURBINE ASSEMBLY 6/2 P/N 098500-1C VEO 0539
AFTER 1391 HOURS OPERATION IN W-1 FACILITY (NASA-LEWIS)
FIRST STAGE WHEEL INLET SIDE

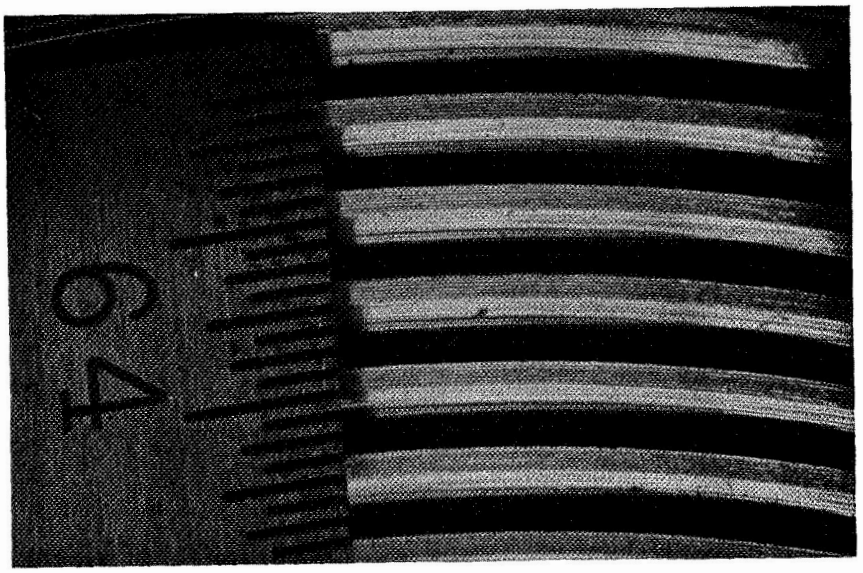
468-093



SEAL GALLING TEST
SHAFT SIMULATOR AND THRUST SEAL OF STELLITE 6B
AFTER 1 HOUR OF RUNNING UNDER 246 GRAM LOAD 3-29-68

Figure 6

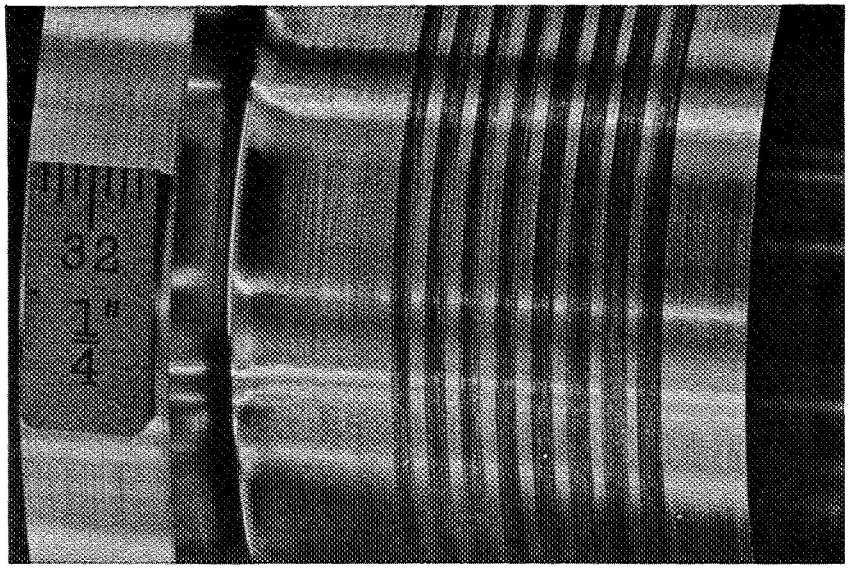
468-092



SEAL TEST
THRUST LABYRINTH SEAL STELLITE 6B
LOAD: 246 GRAMS DURATION: 1 HOUR
AREA OF NO CONTACT 3-29-68

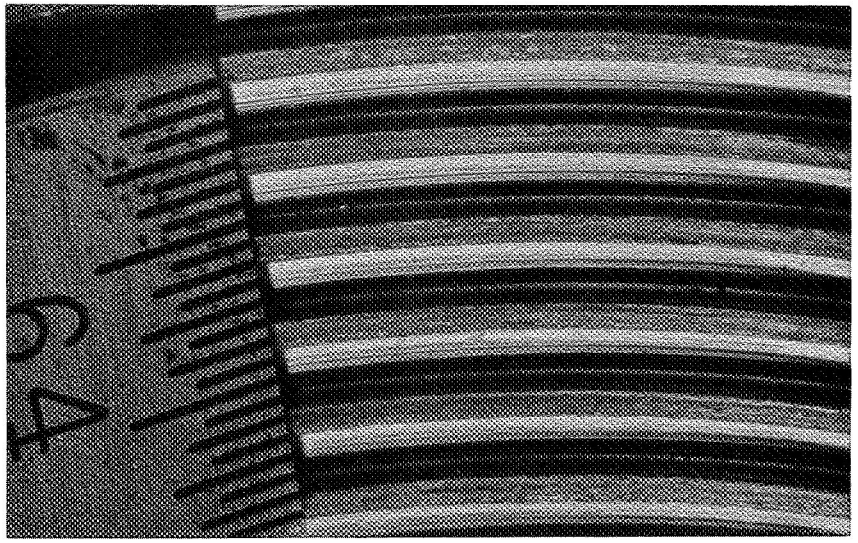
Figure 7

468-096



SEAL TEST
SHAFT SIMULATOR STELLITE 6B
LOAD: 246 GRAMS DURATION: 1 HOUR
AREA OF HEAVIER WEAR 3-29-68

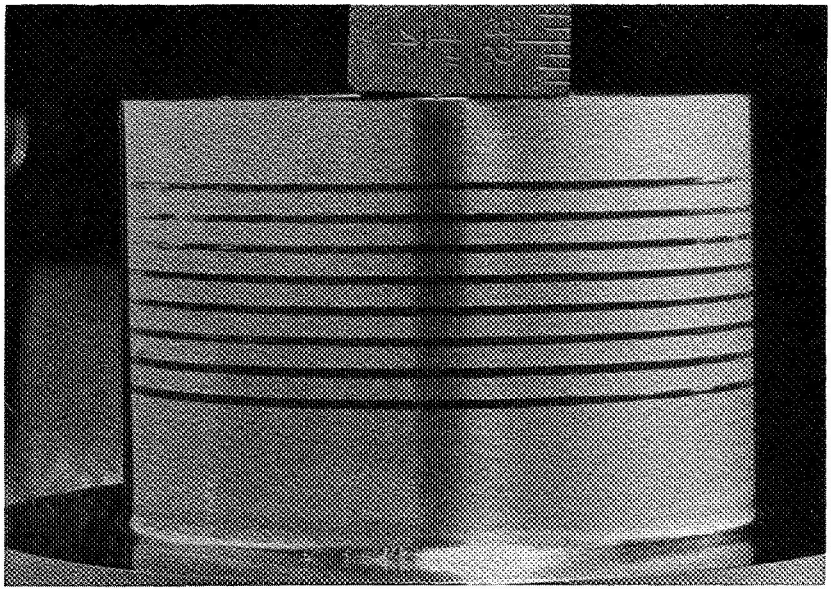
Figure 8a



SEAL TEST
THRUST LABYRINTH SEAL STELLITE 6B
LOAD: 246 GRAMS DURATION: 1 HOUR
AREA IN CONTACT (UNDER THE LOAD)
WITH SHAFT SIMULATOR 3-29-68

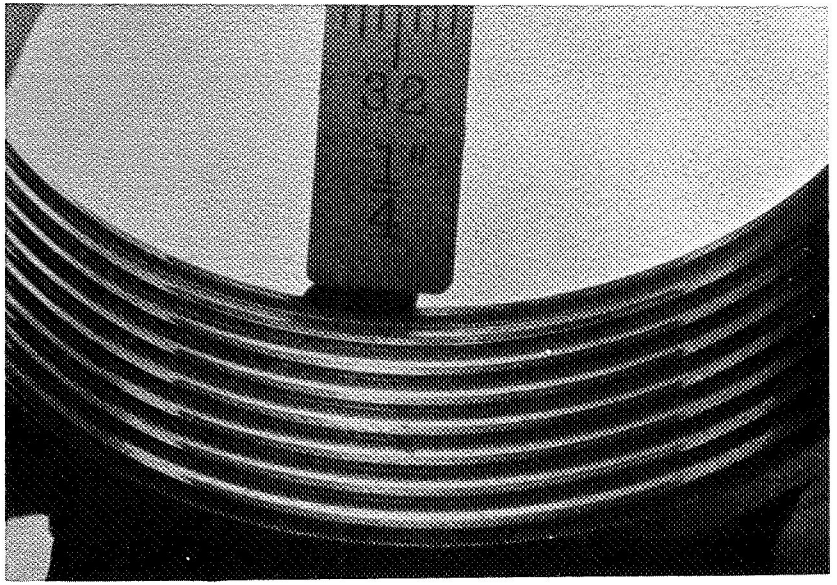
Figure 8b

468-327



SEAL GALLING TEST S816 SHAFT SIMULATOR
LOAD: 256 GRAMS DURATION: 1 HOUR
REGION OF HEAVY WEAR

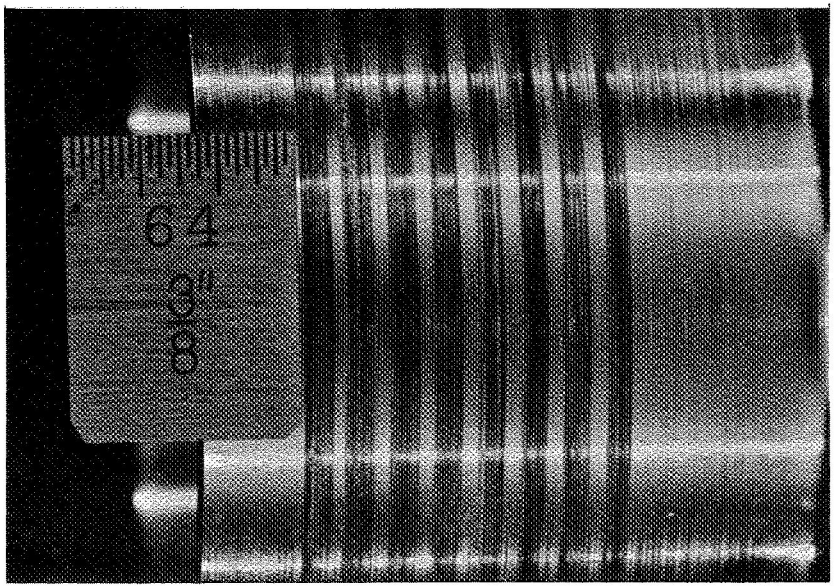
Figure 9a



SEAL GALLING TEST S816 LABYRINTH SEAL
LOAD: 256 GRAMS DURATION: 1 HOUR
REGION OF CONTACT

Figure 9b

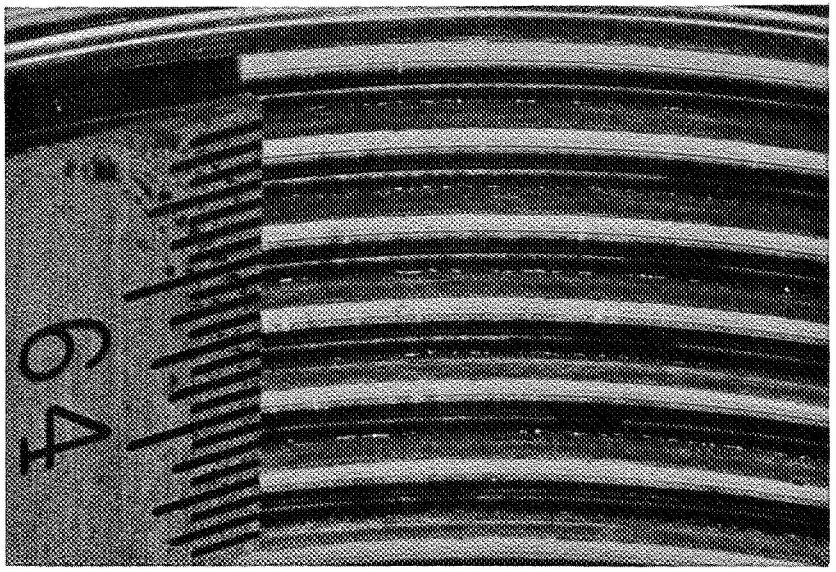
468-588



SEAL GALLING TEST SHAFT SIMULATOR - STELLITE 6B
LOAD: 7000 GRAMS (15.75 LB) DURATION: 10 MINUTES

Figure 10a

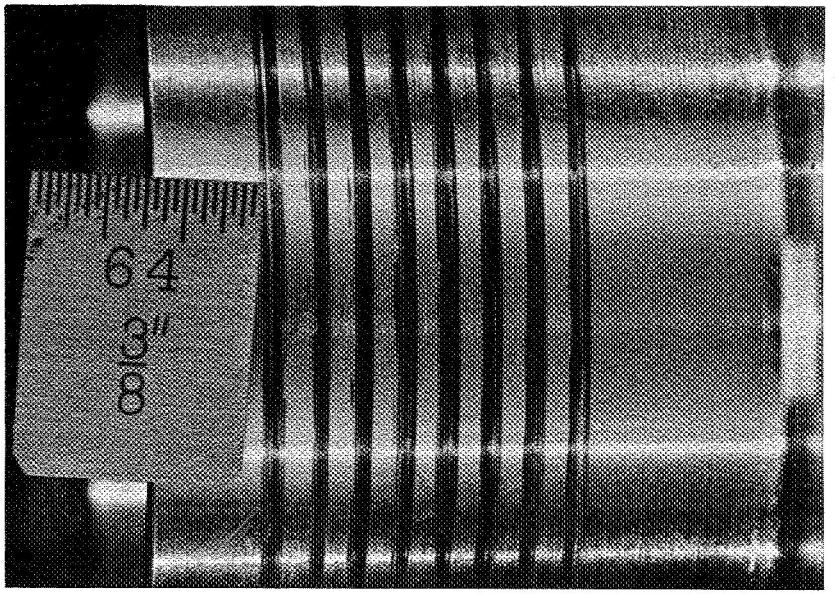
468-589



SEAL GALLING TEST LABYRINTH SEAL - STELLITE 6B
LOAD: 7000 GRAMS (15.75 LB) DURATION: 10 MINUTES
REGION OF CONTACT

Figure 10b

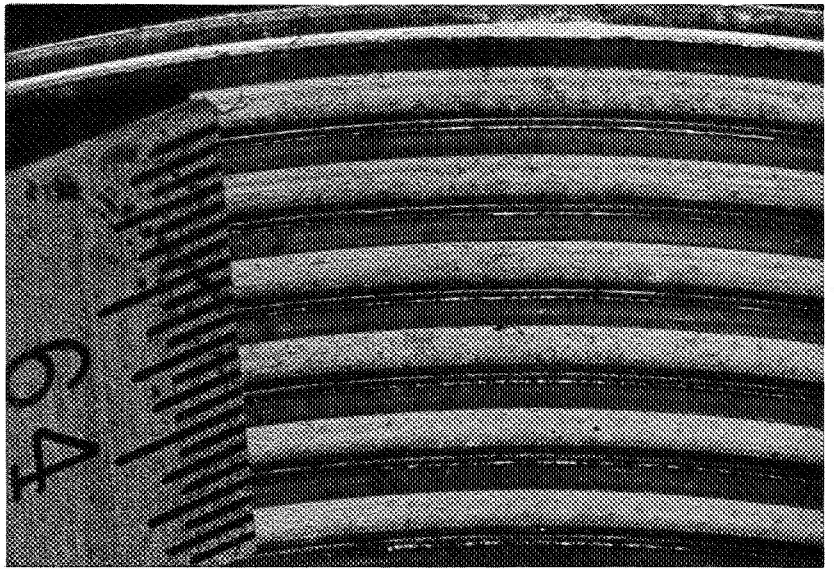
468-591



SEAL GALLING TEST SHAFT SIMULATOR - S816
LOAD: 7000 GRAMS (15.75 LB) DURATION: 10 MINUTES

Figure 11a

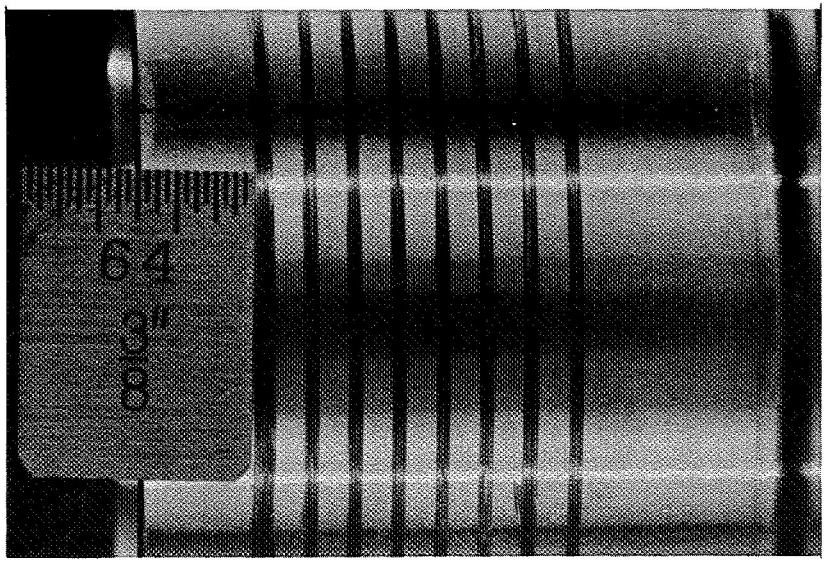
468-590



SEAL GALLING TEST LABYRINTH SEAL - S.816
LOAD: 7000 GRAMS (15.75 LB) DURATION: 10 MINUTES
REGION OF CONTACT

Figure 11b

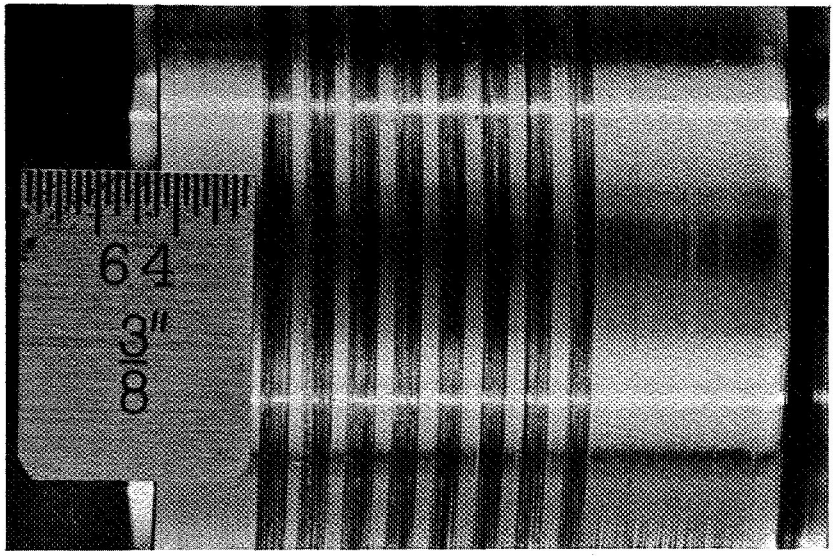
468-615



SEAL GALLING TEST SHAFT SIMULATOR S816
LOAD: 11,000GRAMS (25 LBS) DURATION: 10 MINUTES 4-24-68

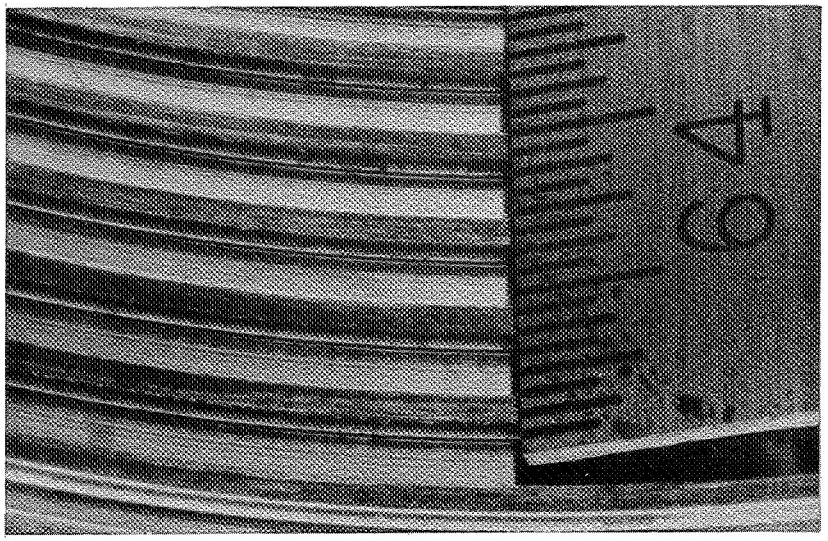
Figure 12a

468-616



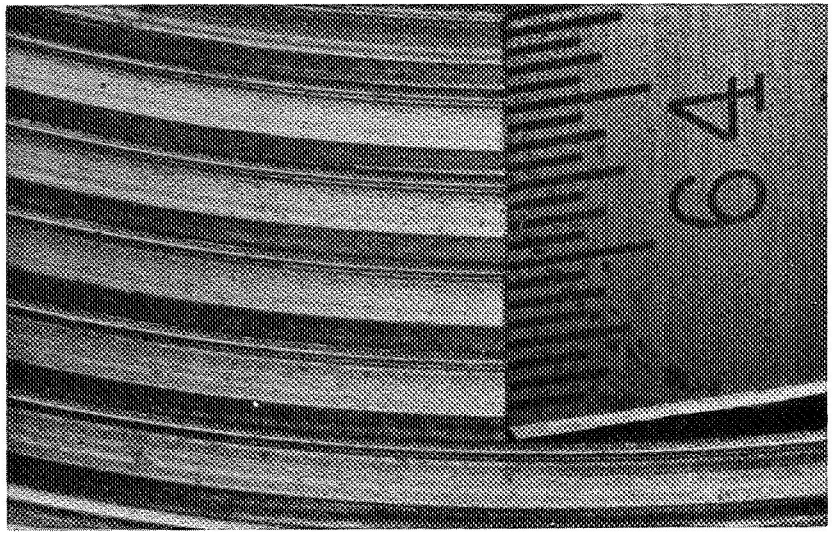
SEAL GALLING TEST SHAFT SIMULATOR STELLITE 6B
LOAD: 11,000 GRAMS (25 LBS) DURATION: 10 MINUTES 4-24-68

Figure 13a



SEAL GALLING TEST THRUST LABYRINTH SEAL STELLITE 6B
LOAD: 11,000 GRAMS (25 LBS) DURATION: 10 MINUTES 4-24-68
AREA IN CONTACT (UNDER THE LOAD)

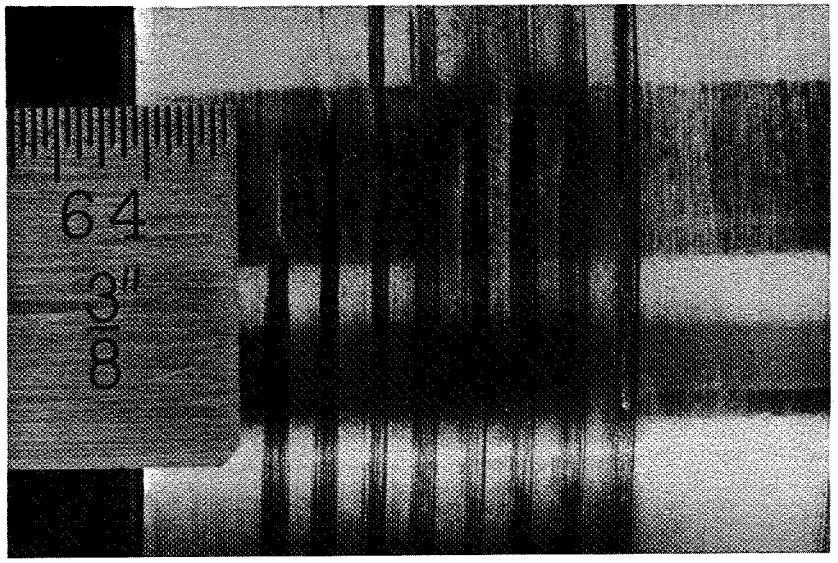
Figure 12b



SEAL GALLING TEST THRUST LABYRINTH SEAL S816
LOAD: 11,000 GRAMS (25 LBS) DURATION: 10 MINUTES 4-24-68
AREA IN CONTACT (UNDER THE LOAD)

Figure 13b

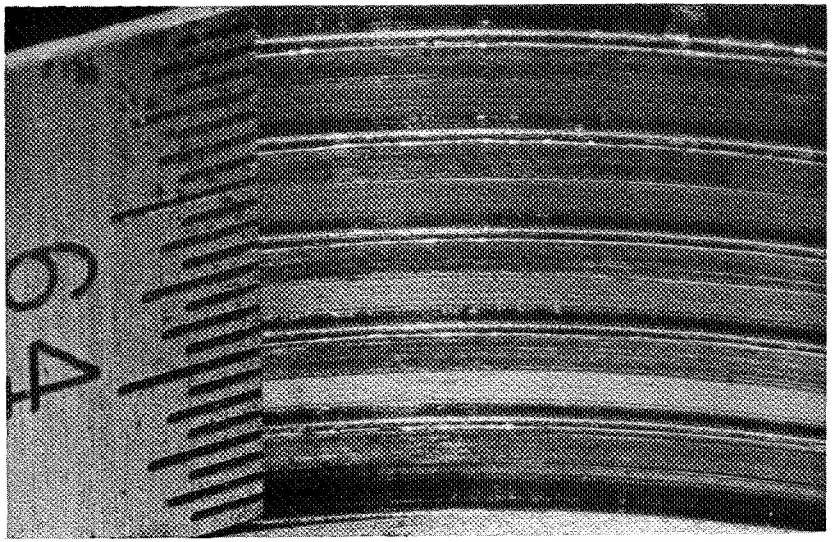
568-282



SEAL GALLING TEST SHAFT SIMULATOR - S816
LOAD: 22,000 GRAMS (~50 LBS.) DURATION: 1.25 MINUTES
5-2-68

Figure 14a

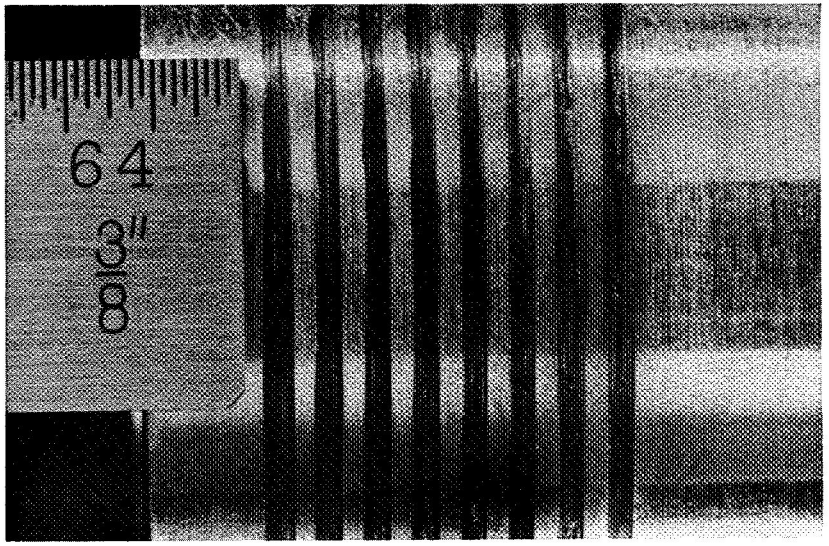
568-279



SEAL GALLING TEST
THRUST LABYRINTH SEAL - STELLITE 6B
LOAD: 22,000 GRAMS (~50 LBS.) DURATION: 1.25 MINUTES
REGION OF CONTACT 5-2-68

Figure 14b

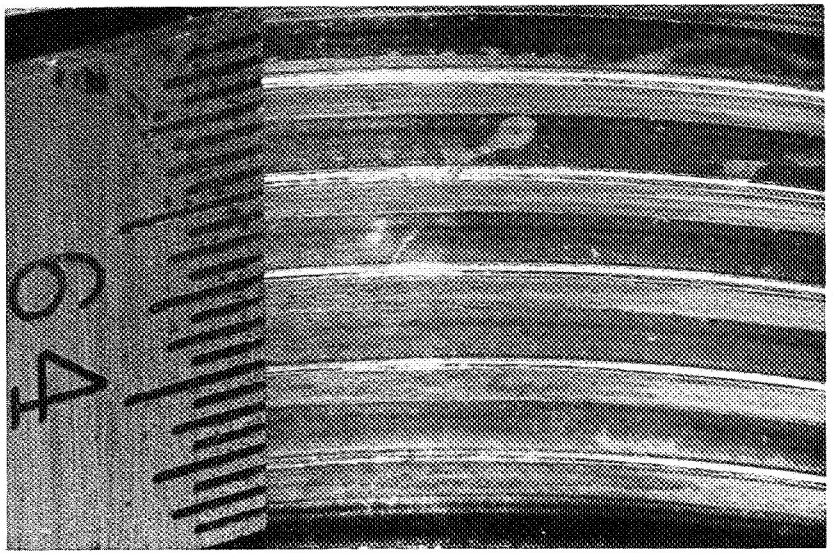
268-583



SEAL GALLING TEST SHAFT SIMULATOR -S816
LOAD: 22,000 GRAMS (~50 LBS.) DURATION: 1.25 MINUTES
5-2-68

Figure 15a

568-280



SEAL GALLING TEST THRUST LABYRINTH SEAL - S816
LOAD: 22,000 GRAMS (~50 LBS.) DURATION: 1.25 MINUTES
REGION OF CONTACT 5-2-68

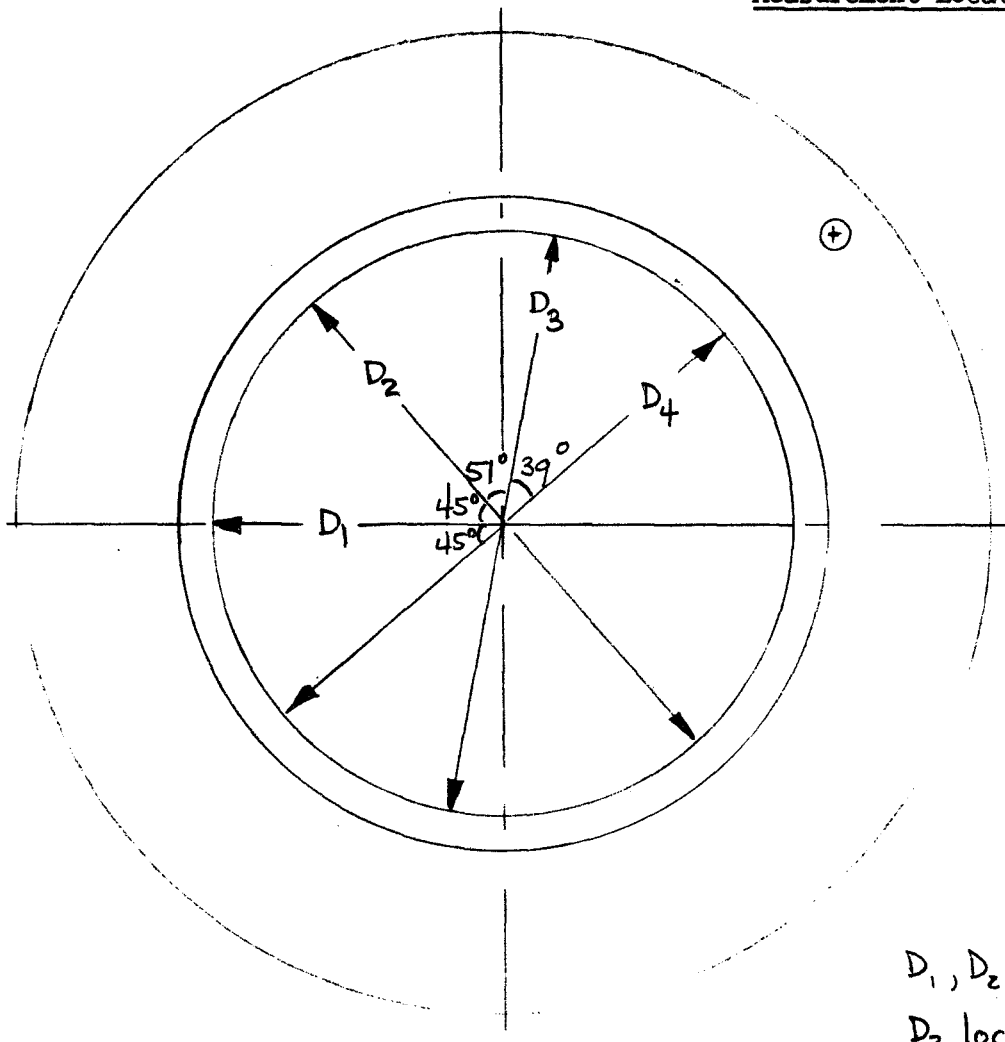
Figure 15b

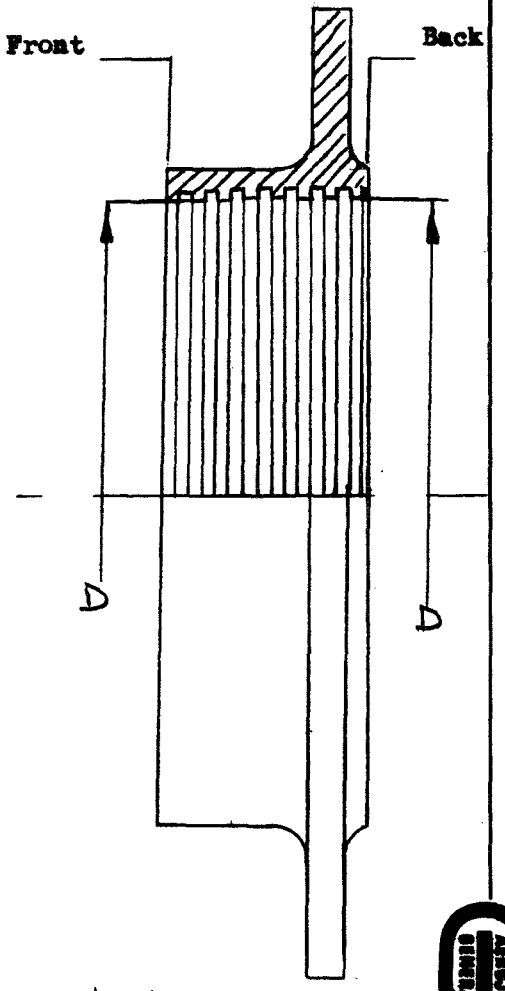
668-X-1188

GALLING TEST

TURBINE THRUST SEAL P/N 099779 & 1264116

Measurement Locations





D_1, D_2 D_3 & D_4; I.D of Seal.

D_3 located directly under applied Load.

Figure 16

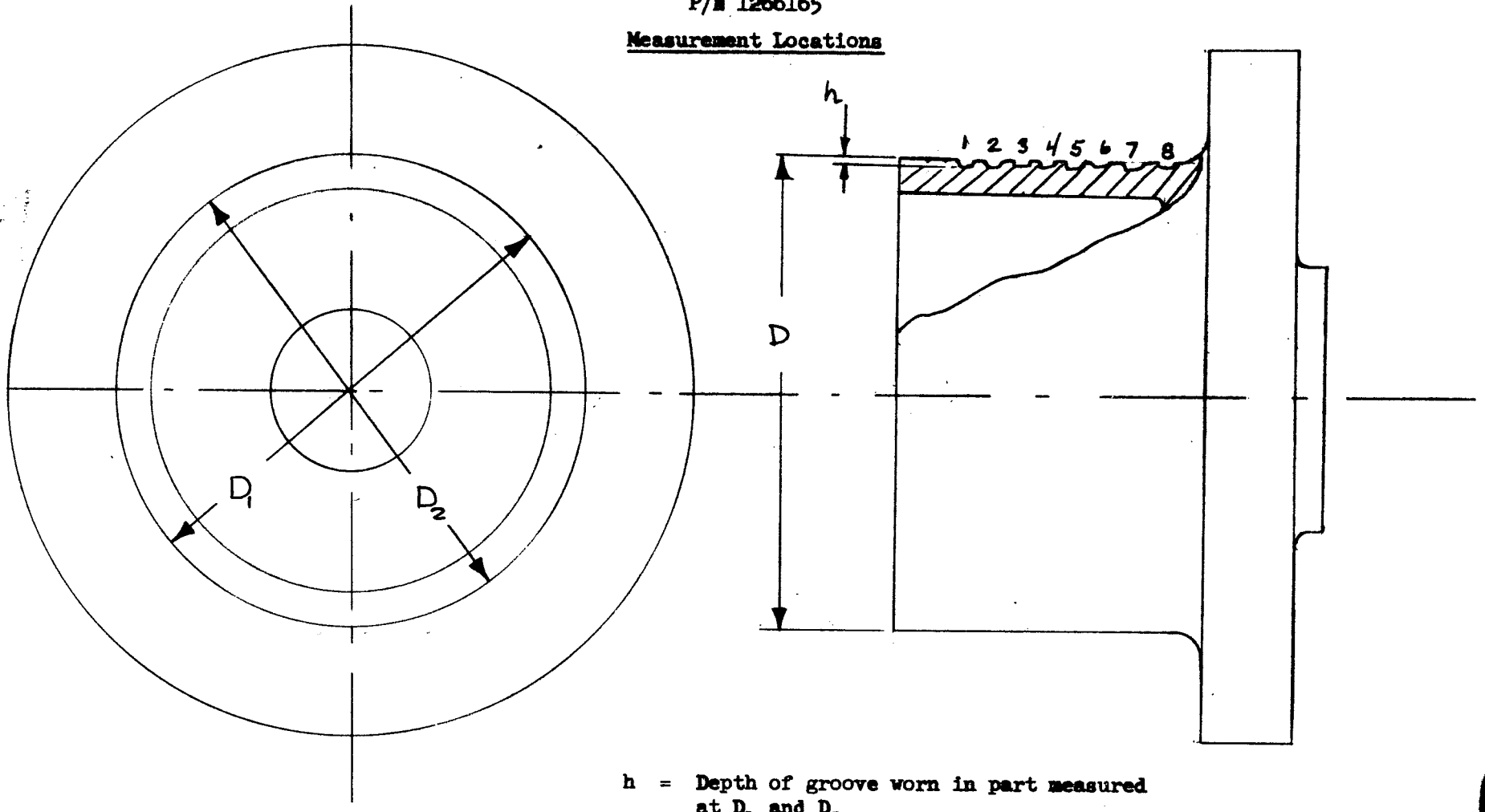
668-X-1189

GALLING TEST

TURBINE SHAFT SIMULATOR

P/N 1266165

Measurement Locations



h = Depth of groove worn in part measured at D_1 and D_2

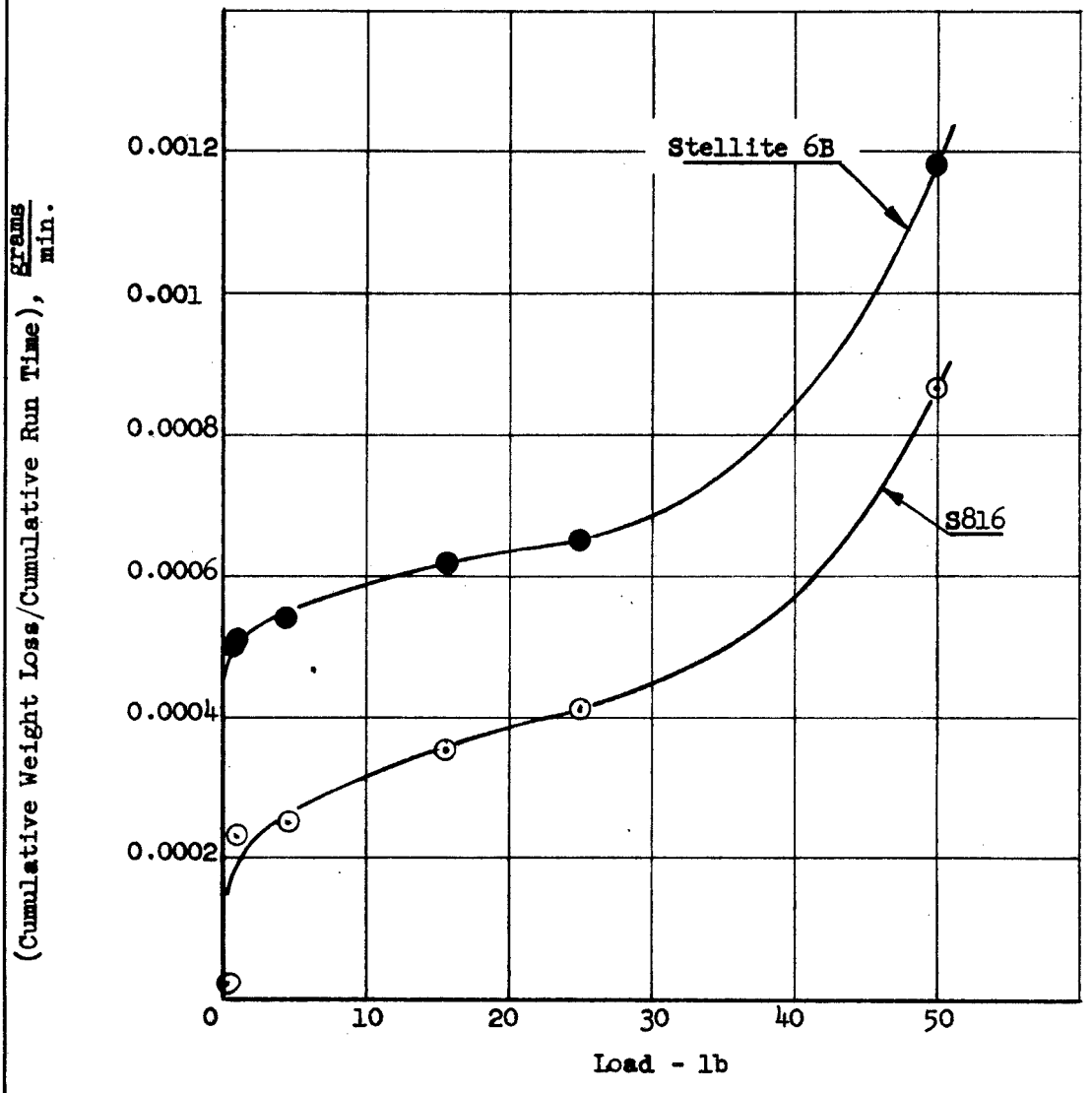
D = D_1 and D_2 diameter across top of grooves

Figure 17

TURBINE LABYRINTH SEAL
GALLING TEST

RATE OF WEIGHT LOSS WITH LOAD
LABYRINTH SEAL

Stellite 6B: P/N 099779-1 S/N A-1
S816: P/N 1264116-1 S/N 1098



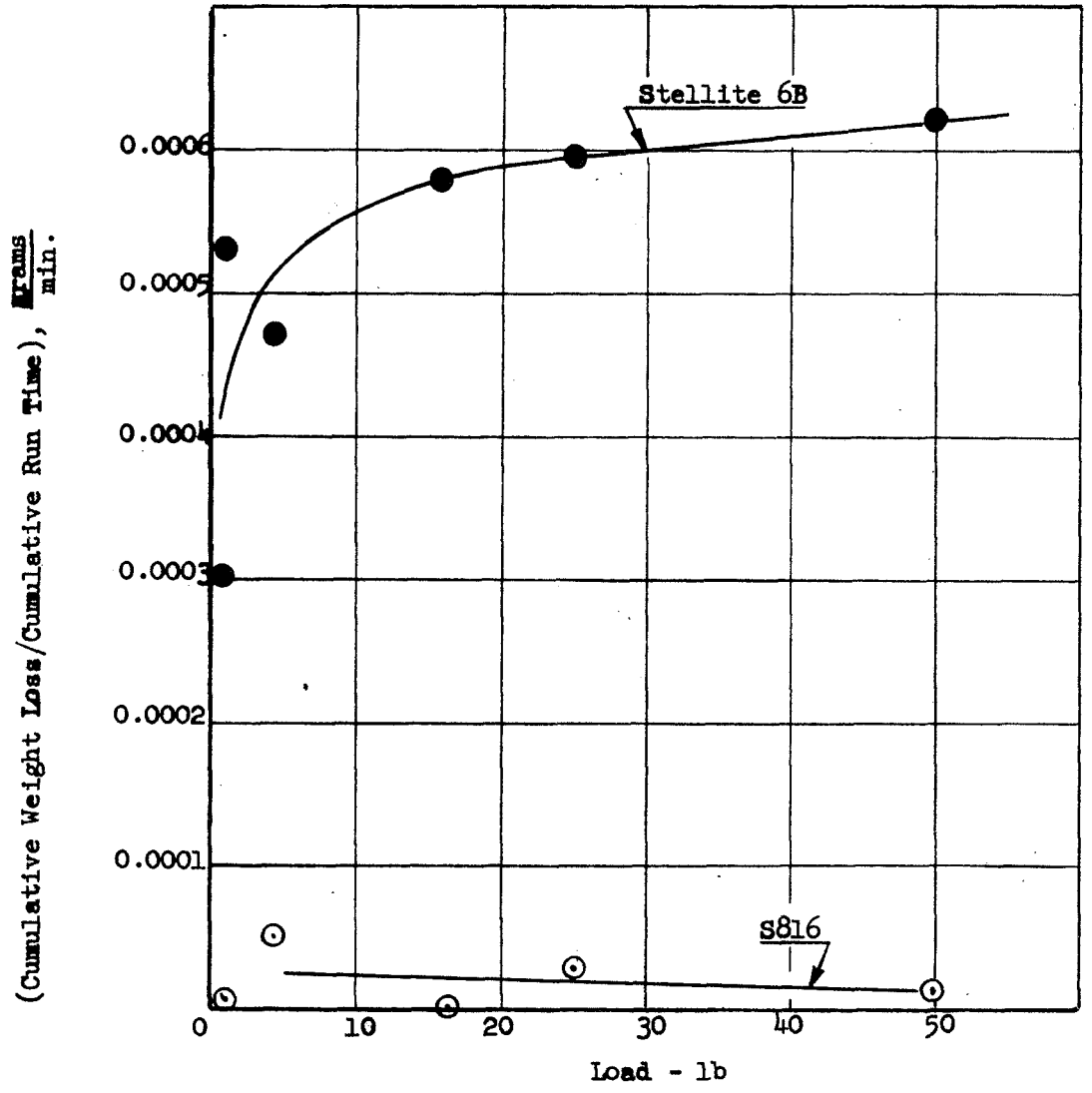
5-6-68
MGC

Figure 18

AEROJET GENERAL

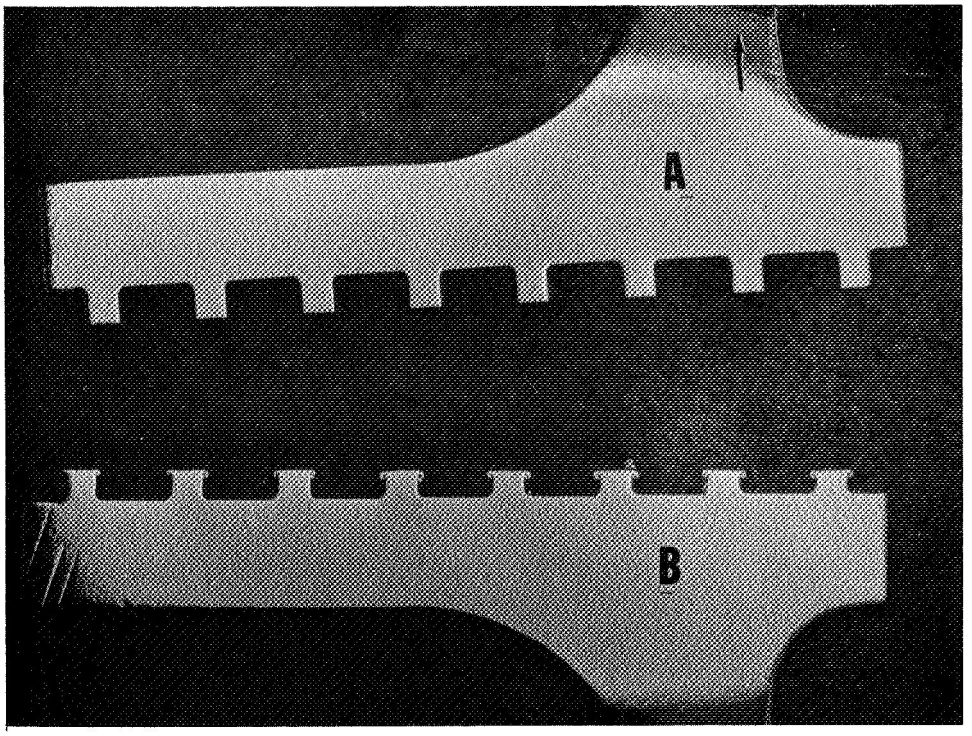
TURBINE LABYRINTH SEAL
GALLING TEST
RATE OF WEIGHT LOSS WITH LOAD
SHAFT SIMULATOR (RUNNER)

Stellite 6B: P/N 1266165-1 S/N A-2
S816: P/N 1266165-2 S/N A-2



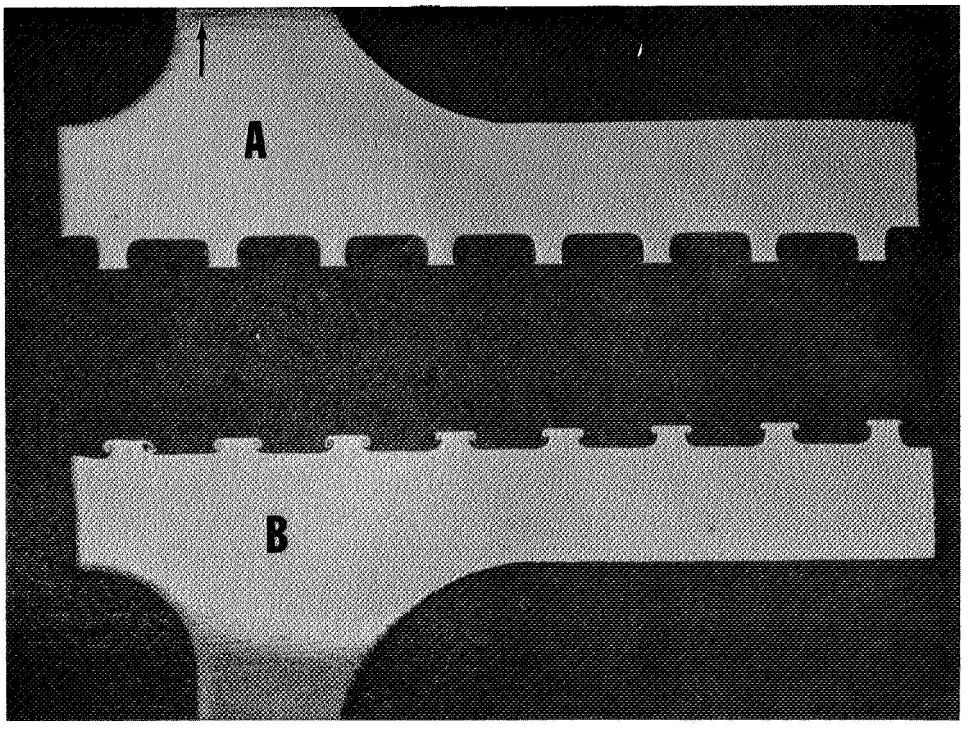
5-6-68
MGC

Figure 19



A2707 8X

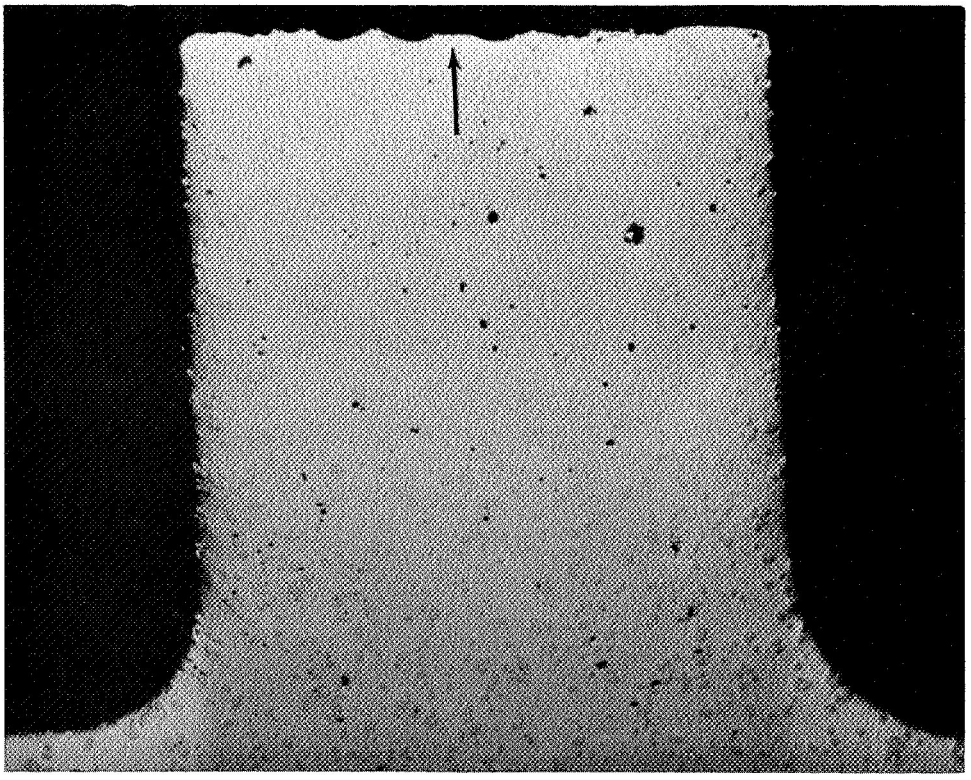
A. Stellite 6B. Section A Unexposed, Section B after Testing. Arrow indicates collar segment.



A2708 8X

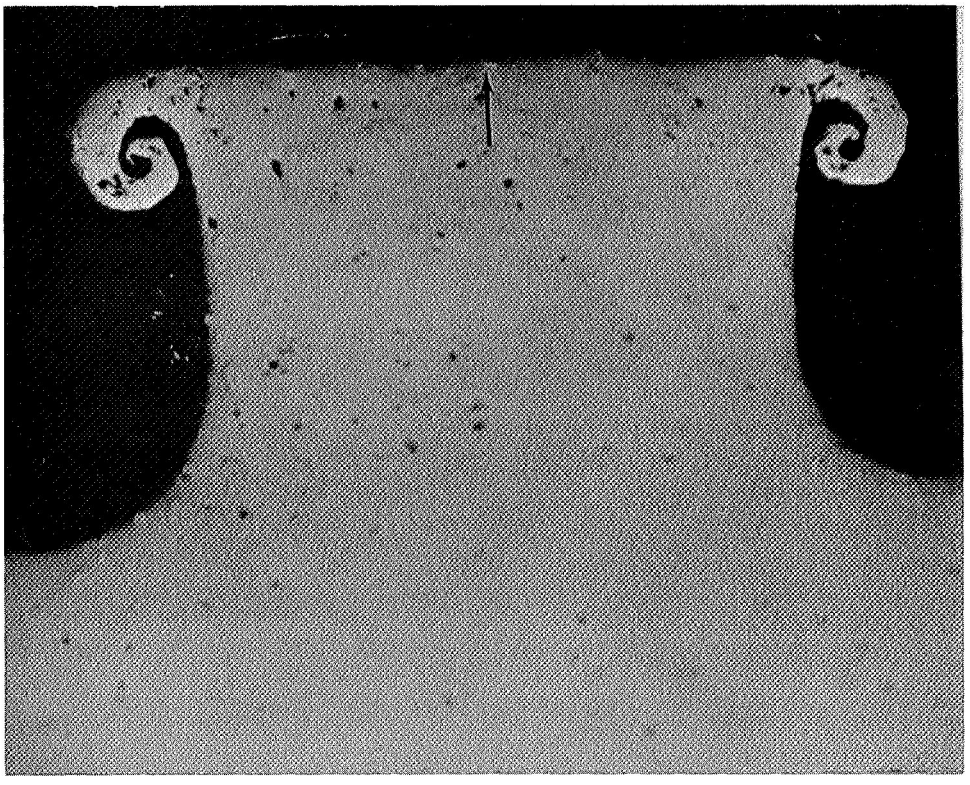
B. S-816. Section A Unexposed, Section B after Testing. Arrow indicates collar segment.

Figure 20. Longitudinal Cross Sections of Stellite 6B and S-816 Superalloy Turbine Labyrinth Seals after Testing at 50 Pounds for 1-1/4 Minutes at 12,000 rpm



A2770 150X

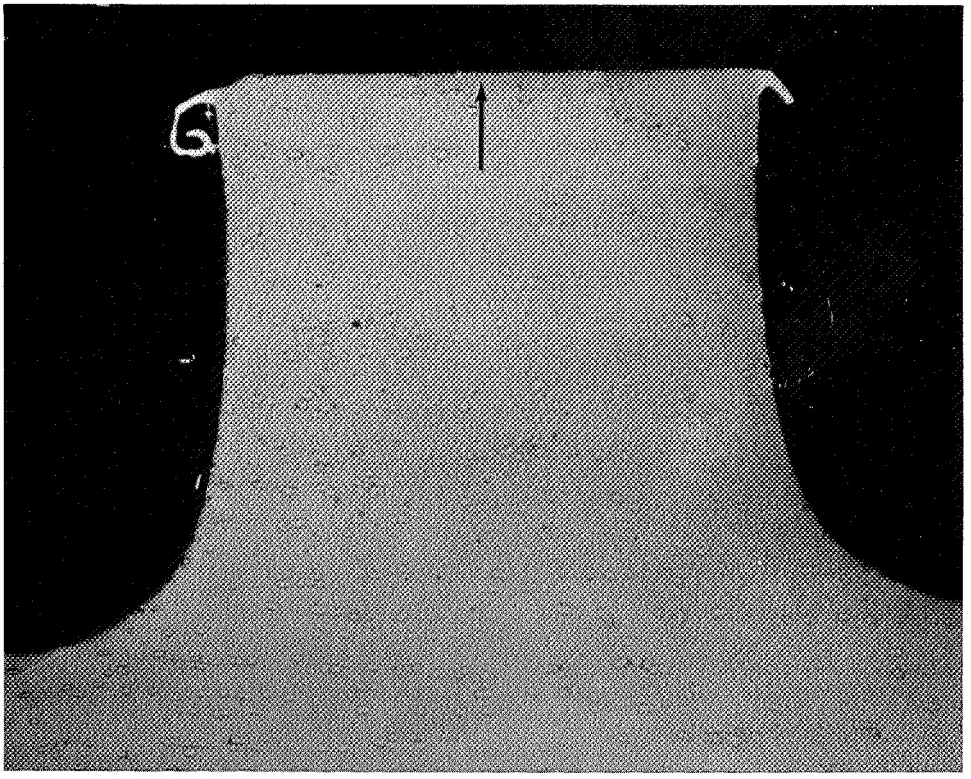
A. Unexposed as-machined contact surface (arrow).



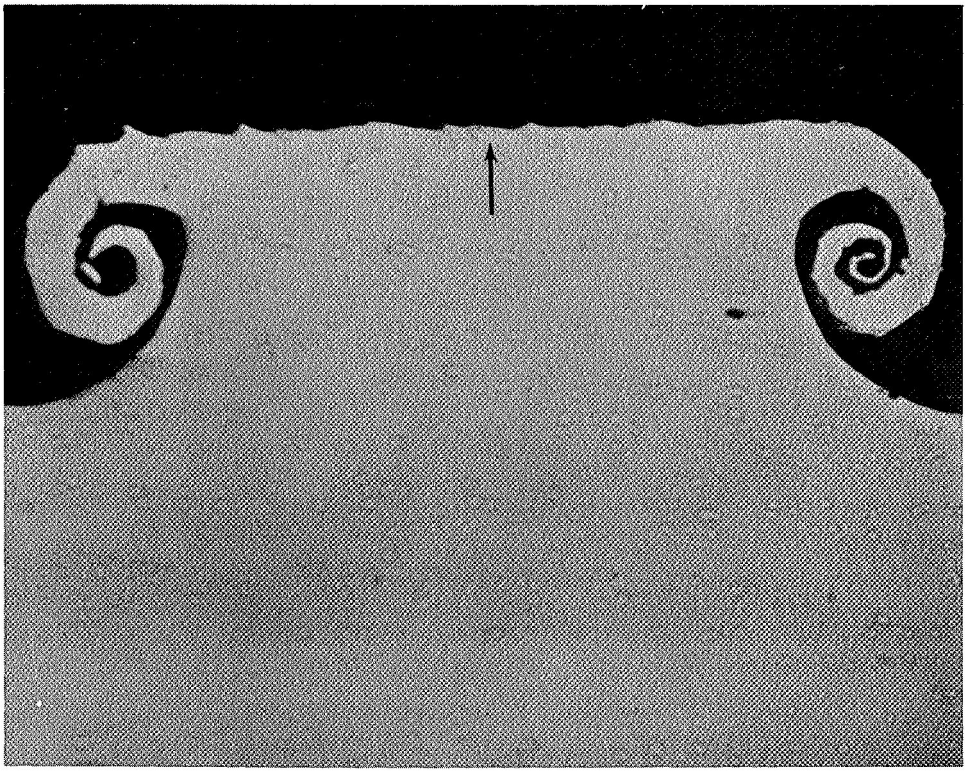
A2771 150X

B. Abraded surface (arrow) after testing.

Figure 21. Cross Sections of Stellite 6B Labyrinth Seal-lands (second from "collar end").

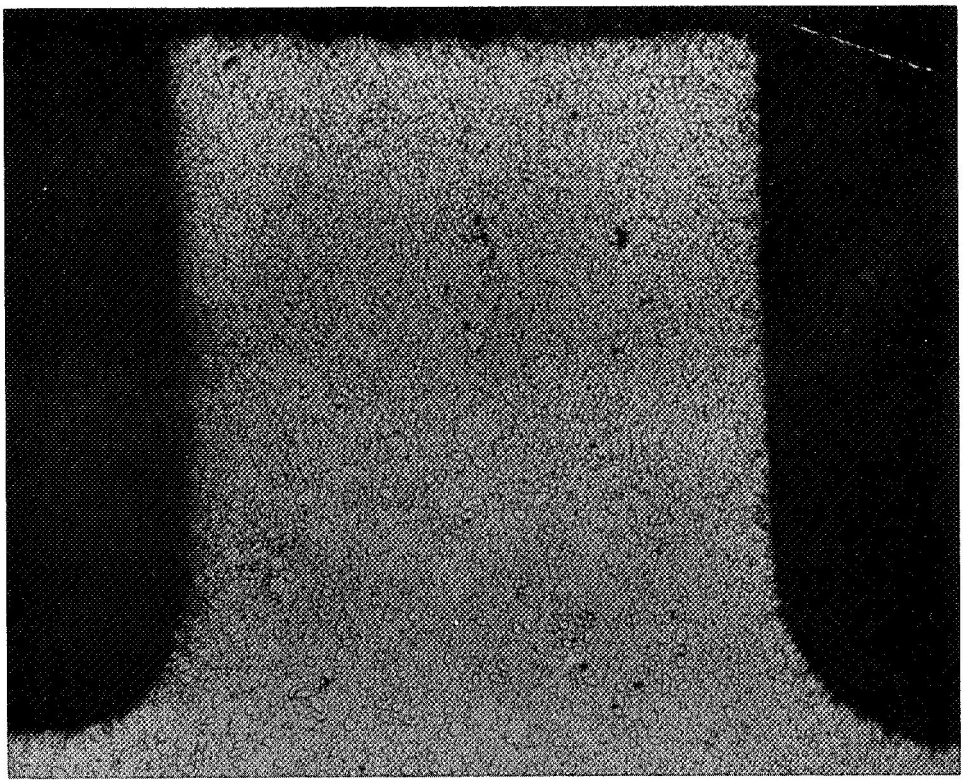


A2772 150X
A. Unexposed as-machined contact surface (arrow) and machining burrs.

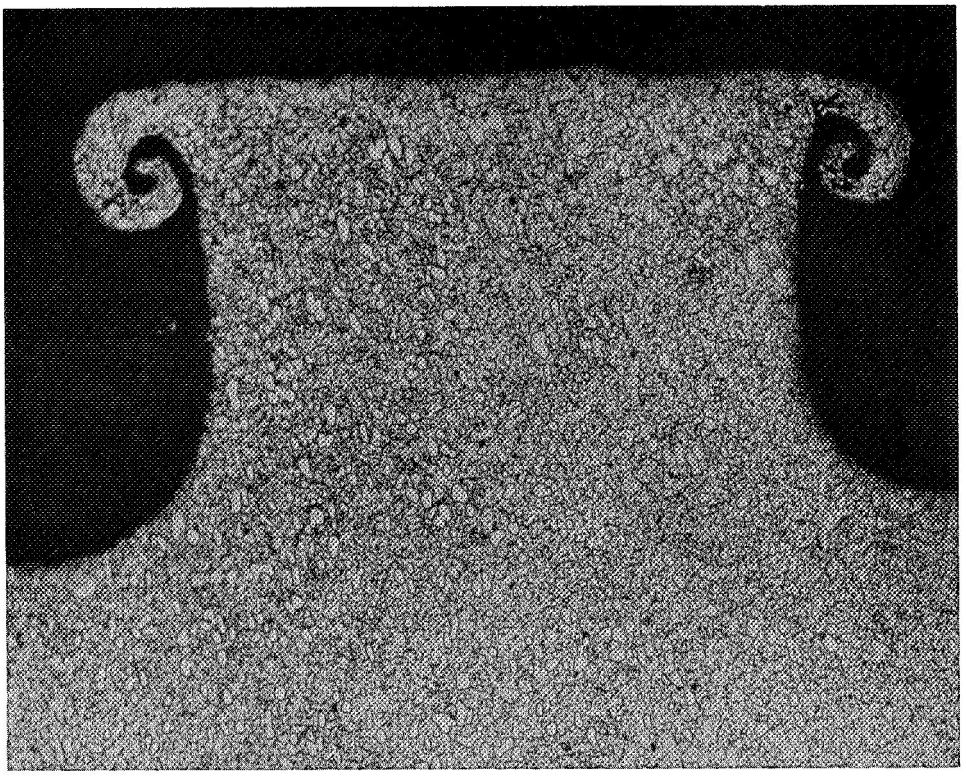


A2773 150X
B. Abraded surface (arrow) after testing.

Figure 22. Cross Sections of S-816 Labyrinth Seal-lands (second from "collar end").

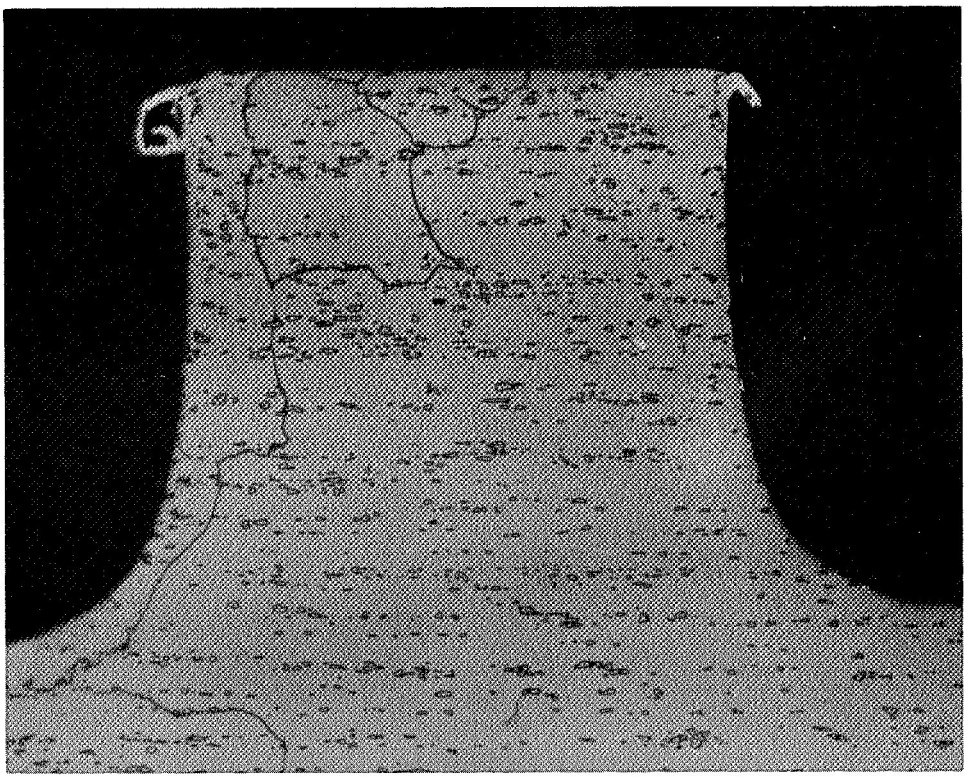


A2777 150X
A. Unexposed surface. ASTM No. 10 grain size.



A2776 150X
B. Abraded surface after testing. ASTM No. 10 grain size.

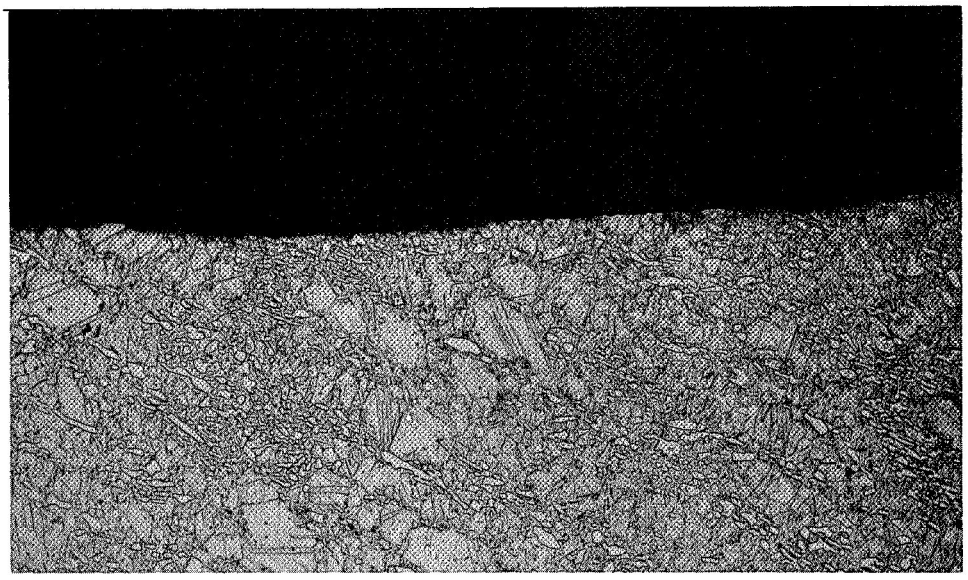
Figure 23. Microstructure of Stellite 6B Labyrinth Seal. Etched in Hydrochloric-Nitric Acid Reagent.



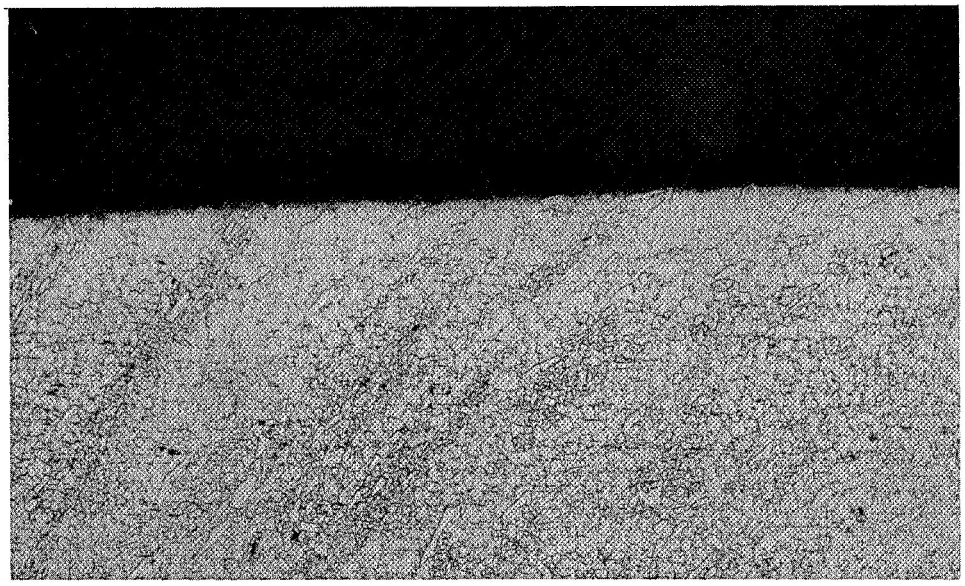
A2775
A. Unexposed surface. ASTM No. 1½ grain size.

A2774
B. Abraded surface after testing. ASTM No. 2 grain size.

Figure 24. Microstructure of S-816 Labyrinth Seal-Etched in Hydrochloric-Nitric Acid Reagent.

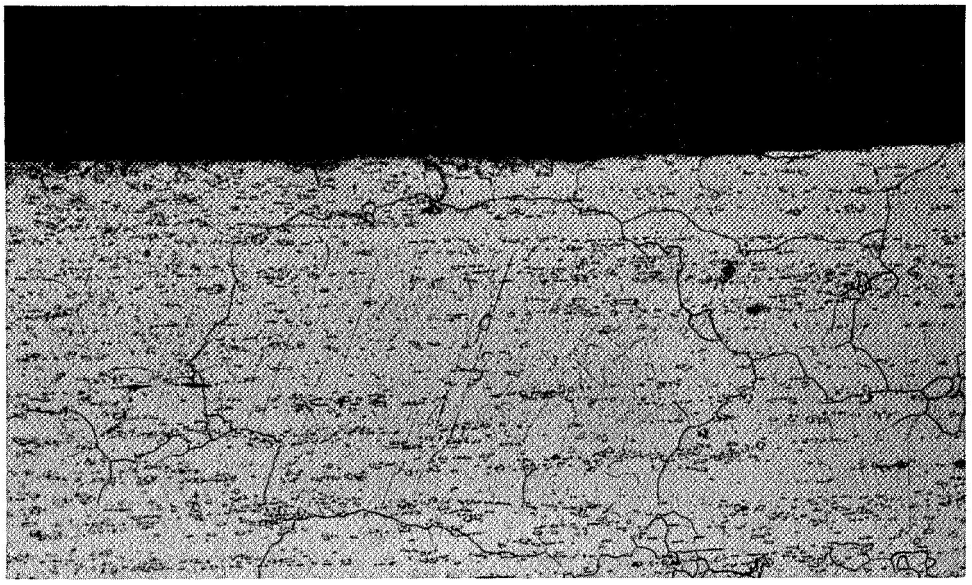


A2715
A. At heat-affected zone (HAZ). ASTM No. $6\frac{1}{2}$ to 10 grain size.

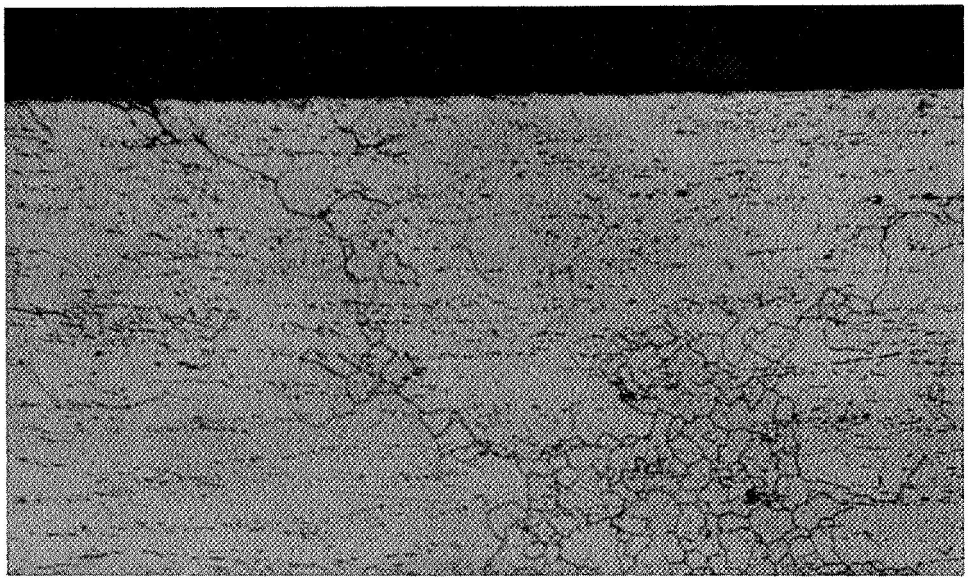


A2719
B. 180° from HAZ. ASTM No. 10 grain size.

Figure 25. Cross Sections of Stellite 6B Runner after Testing. Etched in Hydrochloric-Nitric Acid Reagent.



A2716
A. At heat-affected zone (HAZ). ASTM No. $2\frac{1}{2}$ grain size.



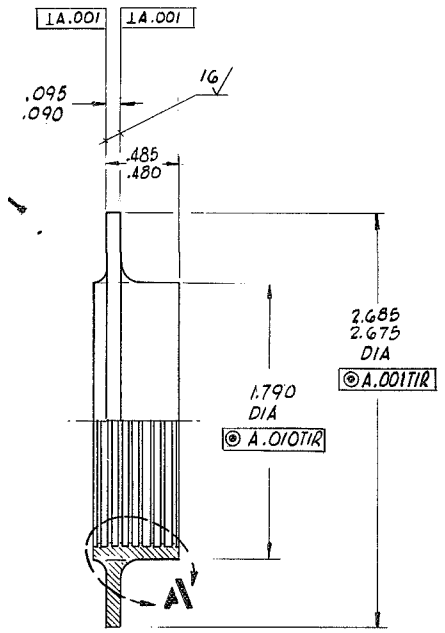
A2724
B. 180° from HAZ. ASTM No. 3 to 8 grain size.

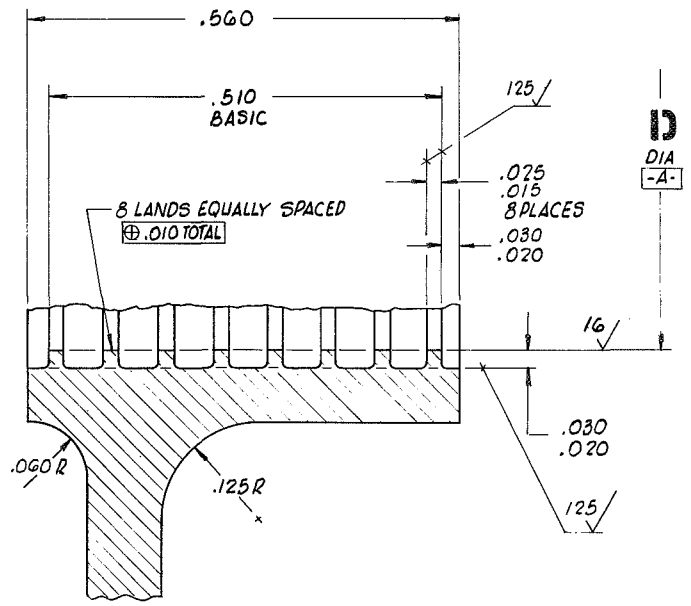
Figure 26. Cross Section of S-816 Runner after Testing. Etched in Hydrochloric-Nitric Acid Reagent.

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED
	A	SEE INC ADCN	11-18-66	
	B	SEE DCN	3-6-67	

NOTES: 1. REMOVE ALL BURRS AND SHARP EDGES EQUIVALENT TO .001/.003 R.

2. INTERPRET DRAWING PER STANDARDS PRESCRIBED IN MIL-D-1000.
3. ALL FILLET RADII TO BE .005-015 UNLESS OTHERWISE SPECIFIED.
4. ALL MACHINED SURFACES TO BE 63 UNLESS OTHERWISE SPECIFIED.
5. BEFORE FINAL MACHINING, HEAT TREAT PART FOR 4 HR AT 1650°F ± 25°F FOLLOWED BY 48 HR AT 1250°F ± 25°F, FOLLOWED BY AIR COOLING TO ROOM TEMPERATURE. AIR COOLING BETWEEN 1650°F & 1250°F TREATMENT IS OPTIONAL. THE HEATING EQUIPMENT USED SHALL BE CERTIFIED TO MIL-H-6875.
6. PENETRANT INSPECT PER MIL-I-6866 TYPE I, METHOD "B". PROPAGATING DEFECTS ARE A CAUSE FOR REJECTION.
7. PACKAGE PER MIL-P-116 METHOD III.
8. TAG PER ASD-5215M WITH 099779, APPLICABLE DASH NO./ (APPLICABLE REVISION LETTER) AND LOT OR SERIAL NO.





DETAIL A
SCALE: 1/1

DASH NO.	D DIA
-1	1.6065 1.6070
-3	1.579 1.580

QTY REQD	SYM	CODE IDENT	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	UNIT WT.	ZONE	ITEM NO.
			-3		FORGING STELLITE 6B	AGC 10210			
			-1		FORGING STELLITE 6B	AGC 10210			

LIST OF MATERIALS

DASH NO.	PART	NEXT ASSY	FINAL ASSY	NEXT ASSY	USED ON
-3	1		126423[illegible]-1	AGAN-0010	
-1	1		126[illegible]64-1	AGAN-0010	
-1	1		099851-1	AGAN0010	

ON THRU
EFFECTIVE SERIAL NO.
USAGE DATA

DRAWING LEVEL 1

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCE ON DECIMALS ANGULAR
.XX ± .03 ± 2°
.XXX ± .010
DO NOT SCALE DRAWING
TREATMENT 5
FINISH
SIMILAR TO 098049 ACT. WT CALC WT

CONTRACT NO. NAS5-417

		DATE
DRAWN	M. Hamachi	7-28-66
CHECK	[illegible]	10-28-66
DESIGN	[illegible]	8-22-66
STRESS/ STRUCTURE	[illegible]	10-26-66
MATERIALS	[illegible]	9-19-66
PRODUCTION	[illegible]	9-27-66
DESIGN ACTIVITY APPD	[illegible]	10-27-66
ENGINEER QA	G. Takasaki	10-9-66

AEROJET-GENERAL CORPORATION
AZUSA, CALIFORNIA

TITLE
SEAL,
THRUST REDUCTION-
TURBINE

DWG SIZE D | CODE IDENT NO. 70143 | DWG NO. 099779
SCALE 2/1 NOTED | RELEASE DATE 10-31-66 | SHEET

Figure 27